Chapter 3. Affected Environment and Environmental Consequences

3.1 Introduction

This chapter describes the existing conditions of the environmental resources (e.g., hydrologic, biologic, and socioeconomic) of the Basin, followed by an analysis of the extent and magnitude of potential effects on each resource from the alternatives described in **Chapter 2**. Only resources that could potentially be significantly affected by the alternatives are analyzed. Resources considered for analysis but determined not to be significantly affected include the following:

- **Transportation** – No impacts on transportation, apart from the Lake Powell ferry, are anticipated in the analysis area, as the proposed changes are operational in nature. Impacts on the Lake Powell ferry are analyzed in the recreation section.
- **Minerals** – No impacts on minerals or mineral rights are anticipated because all proposed Lake Powell and Lake Mead operational changes and their associated releases and elevations would not affect minerals or mineral rights.
- **Noise** – No impacts on noise are anticipated in the analysis area, as existing noise conditions are expected to continue at the same level under all proposed Lake Powell and Lake Mead operational changes.
- **Light** – No impacts on light are anticipated in the analysis area, as existing light conditions are expected to remain unchanged under all proposed Lake Powell and Lake Mead operational changes.

Section 3.2, Analysis Methods, describes the approach used for assessing the environmental consequences, including the geographic and temporal scope, alternatives and a comparative baseline, and modeling. This is followed by the individual resource sections, which represent a summarized overview of the affected environment and environmental consequences. Further information for each resource section can be found in the corresponding technical appendices identified in each section.

3.2 Analysis Methods

3.2.1 Geographic Scope

Consistent with the geographic scope analyzed in the 2007 Interim Guidelines FEIS, the geographic scope that would be affected by the proposed federal action begins at full pool of Lake Powell at Gypsum Canyon and extends downstream along the mainstream Colorado River floodplain to the Southerly International Boundary (SIB) with Mexico. This proposed federal action would also potentially affect interests of water users in the Lower Division States in service areas that extend beyond the Colorado River floodplain.

Although the proposed federal action is focused on Lake Powell and Lake Mead operations, management strategies that include activities upstream of Lake Powell are being analyzed in this Draft EIS. These activities include Upper Basin conservation and, if warranted to protect critical reservoir elevations, operations at the Colorado River Storage Project (CRSP) Upper Initial Units (see **Map 1-1**). Operations at the CRSP Upper Initial Units specifically contemplated in the Draft EIS alternatives are intended to remain within the scope of the existing Records of Decision (Reclamation 2006a, 2006b, 2012).[1] [2] Accordingly, the Draft EIS does not expand the geographic scope of analysis upstream of Lake Powell. With respect to Upper Basin conservation, the nexus to the proposed federal action is the storage and delivery of that conserved water in Lake Powell. The effects of this storage in and delivery from Lake Powell are within the scope of the EIS (see **Section 3.3**, Hydrologic Resources, and **TA 3**, Hydrologic Resources), while specific activities that may be undertaken in the Upper Basin to generate the conserved water are not within the scope of this EIS. Any such activities are unknown at this time and will not necessarily require federal decision making. Any federal decisions associated with these conservation activities will be assessed outside of this EIS.

For ease of discussion with respect to the geographic scope of this Draft EIS and the affected areas and potential effects, the Colorado River has been divided into nine reaches, as shown on **Table 3-1** and **Map 3-1**.

In addition to effects within the mainstream Colorado River corridor, the water supply to certain Colorado River water users in the Lower Basin along the mainstream of the Colorado River (e.g., water users in the Yuma, Arizona area) and in adjacent service areas may be affected due to water delivery reductions. The following water agency service areas are included in the geographic scope of this analysis as appropriate for affected resources (**Map 3-1**):

- CAP contract service areas, including the Central Arizona Water Conservation District and tribal service areas;
- SNWA service area;
- MWD service area; and
- Imperial Valley and Coachella Valley service areas.

Additionally, numerous tribes hold Colorado River water entitlements and could be affected by water supply availability.

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[1] RODs for CRSP Upper Initial Units include those for Flaming Gorge, Blue Mesa (a component of the Aspinall Unit), and Navajo reservoirs.

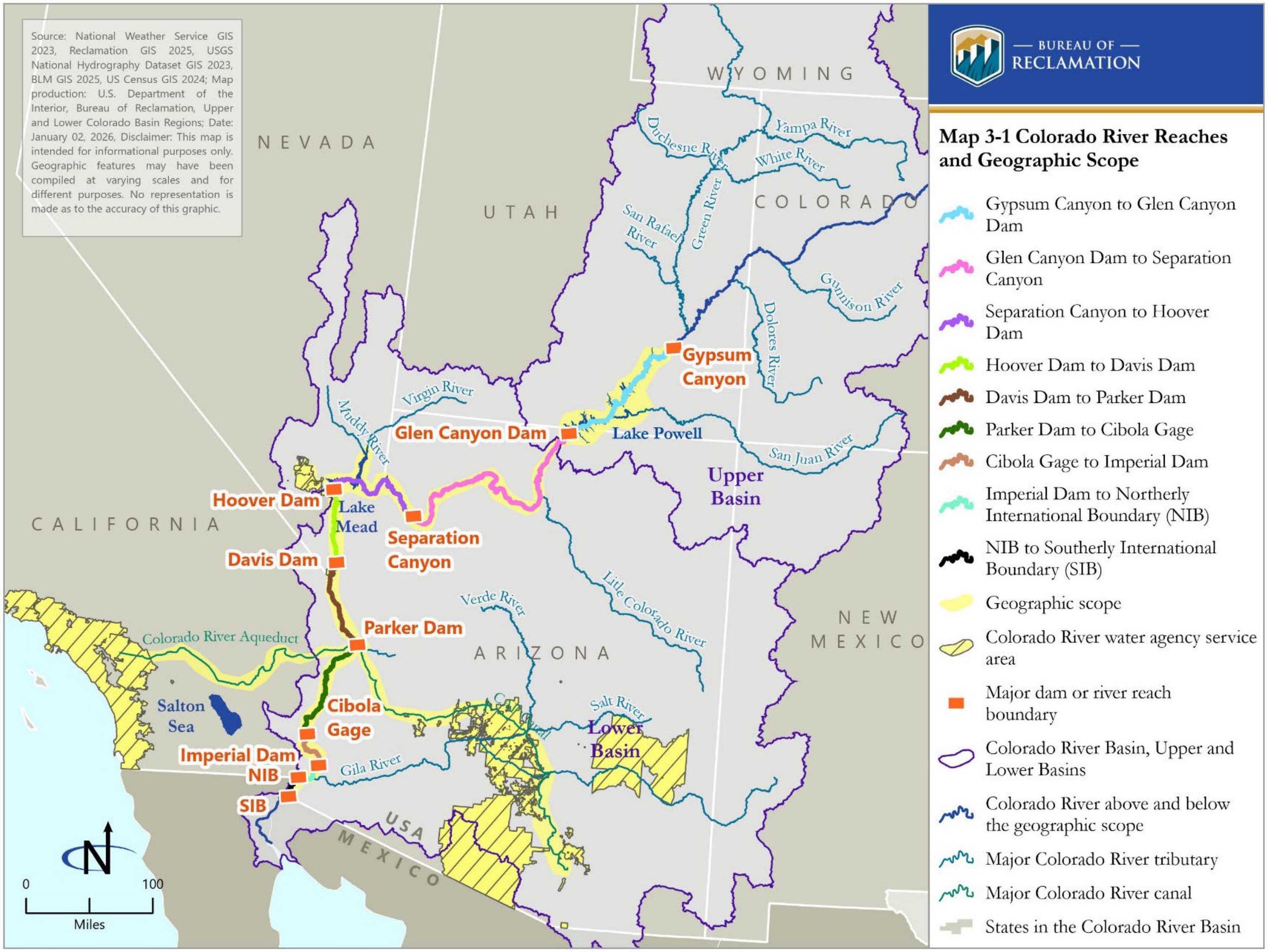
[2] While the Secretary will consider and prioritize operations at these facilities that are consistent with existing RODs, the Secretary retains the authority to operate outside those RODs if necessary. The modeling assumptions regarding operation of the CRSP Upper Initial Units presented in this Draft EIS are not intended to, and do not, limit the Secretary's ability to operate these facilities as necessary to respond to hydrologic conditions in accordance with applicable federal law, including operations for the authorized purposes as stated in the 1956 Colorado River Storage Project Act.

Table 3-1
Colorado River Reaches and Reach Limits in the Geographic Scope

Reach	Reach Limits
Lake Powell and Glen Canyon Dam	Gypsum Canyon to Glen Canyon Dam (RM -15.8)
Glen Canyon Dam to Lake Mead	Glen Canyon Dam (RM -15.8) to Separation Canyon (RM 240), including GCNP
Lake Mead and Hoover Dam[1]	Separation Canyon (RM 240) to Hoover Dam, including Lake Mead
Hoover Dam to Davis Dam	Hoover Dam (RM 342.2) to Davis Dam (RM 276), including Lake Mohave
Davis Dam to Parker Dam	Davis Dam (RM 276) to Parker Dam (RM 192.3), including Lake Havasu
Parker Dam to Cibola Gage (Adobe Ruin)	Parker Dam (RM 192.3) to Adobe Ruins and Reclamation's Cibola Gage (RM 87.3)
Cibola Gage to Imperial Dam	Reclamation's Cibola Gage (RM 87.3) to Imperial Dam (RM 49.2)
Imperial Dam to Northerly International Boundary (NIB)	Imperial Dam (RM 49.2) to the NIB (RM 23.1)
Northerly International Boundary (NIB) to Southerly International Boundary (SIB)	NIB (RM 23.1) to SIB (RM 0.0)

[1] For purposes of this EIS, RMs are measured differently along the length of the Colorado River in the Upper and Lower Basins. RMs in the Upper Basin begin at Glen Canyon Dam and increase from north to south. The Lower Basin RMs count south to north, beginning at RM 0.0 at the SIB with Mexico and increasing to RM 342.2 at Hoover Dam. This system of identifying RMs is consistent with common practices within each Basin. Dam locations, reach limits, and other features are identified at their respective RM.

Map 3-1
Colorado River Reaches and Geographic Scope



3.2.2 Temporal Scope

For purposes of analysis, the temporal scope of this EIS extends from 2027 through 2060, providing a framework for assessing short-term to long-term effects.

3.2.3 Alternatives Analyzed and Comparative Baseline

The analysis for each resource section focuses on specific issues identified during internal and public scoping (Reclamation 2023b). Impact analysis is provided for all the "action alternatives" described in **Chapter 2** (Basic Coordination Alternative, Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative), along with the No Action Alternative. A No Action Alternative typically serves as an extension of current operations to provide a benchmark to compare the extent and magnitude of the impacts from each action alternative. However, as described in **Chapter 2**, due to the expiration of current domestic and international implementing agreements, the No Action Alternative represents a change in operations. As such, the No Action Alternative in this EIS does not serve as an appropriate baseline to compare impacts. To address this challenge, a CCS Comparative Baseline scenario is provided to assess the impacts if operations continued under the current direction and strategies.[3] While the CCS Comparative Baseline is not an action alternative, it is a contemporary set of operations that stakeholders are familiar with that can be used to comparatively evaluate the performance of the alternatives (including the No Action Alternative).

The key modeling assumptions for the CCS Comparative Baseline are summarized in **Table 3-2** and additional details are included in **Appendix A**, CRSS Model Documentation. These modeling assumptions were designed to reflect a continuation of the primary existing agreements for Colorado River management including the 2007 Interim Guidelines, the 2019 DCP and Minute 323 of the 1944 Water Treaty.

[3] This framework relies on strategies and agreements that expire in 2026, including the 2007 Interim Guidelines (as amended), the 2019 DCP, Minute 323 of the 1944 Water Treaty, and other agreements.

Table 3-2
Summary of the CCS Comparative Baseline

Shortage Guidelines to Reduce Deliveries from Lake Mead[1]	Coordinated Reservoir Operations (Lake Powell and Lake Mead)	Storage and Delivery of Conserved System and Non-system Water (Lake Mead and/or Lake Powell)[1]	Surplus Guidelines to Increase Deliveries/Releases from Lake Mead[1]	Additional Activities Above Lake Powell
• Shortages determined based on Lake Mead elevation • Shortage volume of 400, 500, and 600 kaf at elevations 1,075, 1,050, and 1,025 feet, respectively • DCP and Binational Water Scarcity Contingency Plan contributions ranging from 241 kaf at elevation 1,090 feet to 750 kaf at elevation 1,025 feet • Shortages and DCP contributions distributed based on existing agreements	• Lake Powell releases are determined based on Lake Powell and Lake Mead elevations • 3 tiers of releases ranging from 9.5 to 7.0 maf with potential adjustments down to 6.0 maf for infrastructure protection • Equalization tier with higher releases possible at higher Lake Powell elevations	• Storage up to 4.2 maf in Lake Mead • Delivery of existing ICS assumed to continue through the analysis period (2027-2060) in accordance with existing agreements designed to reflect the historical range of use of the ICS mechanism • Creation of ICS assumed to continue through the analysis period (2027-2060) in accordance with existing agreements designed to reflect the historical range of use of the ICS mechanism	• Surplus determinations based on Lake Mead Elevation at or above 1,145 feet: Domestic Surplus, 70R (spill avoidance strategy), , Flood Control Conditions, and increases in deliveries to Mexico per Minute 323	• Releases from CRSP Upper Initial Units within their respective RODs and contingent on hydrologic conditions to protect infrastructure at Glen Canyon Dam

[1]These operational elements contain modeling assumptions for water deliveries to Mexico. Shortage volumes include assumptions related to reductions in water deliveries to Mexico based on Minute 323. Lake Mead storage volumes for the Storage and Delivery of Conserved System and Non-system Water include assumptions related to storage available to Mexico. Surplus Guidelines include assumptions related to increased deliveries to Mexico based on Minute 323. **Appendix A** provides additional detail. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current United States policy or a determination of future United States policy regarding deliveries to Mexico. The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

3.2.4 Hydrologic Modeling

Hydrologic modeling of the Colorado River system was conducted to determine the potential hydrologic effects of the alternatives considered in this Draft EIS. The hydrologic modeling provides projections of potential future Colorado River system conditions (such as reservoir elevations, reservoir releases, and river flows) under the No Action Alternative (and the CCS Comparative Baseline) for comparison with conditions simulated for the action alternatives. Due to uncertainties associated with future inflows, which are the largest driver of system outcomes under any given operation, hundreds of simulations were performed for each alternative to explore how each responds to a range of plausible future conditions. The simulations and analysis framework were designed to avoid reliance on narrow hydrologic assumptions, ensure meaningful comparison between alternatives, and provide reliable information about how the system would respond under each alternative. Hydrologic modeling is the driver for various resource impacts and is therefore the basis for analyzing potential effects on other environmental resources (e.g., recreation, biological resources, and energy). The potential effects on specific resource issues are identified for each alternative and compared with those under the No Action Alternative and CCS Comparative Baseline.

Hydrologic Model Description

Future Colorado River system conditions under the No Action Alternative, CCS Comparative Baseline, and the action alternatives were simulated using CRSS. CRSS, implemented through RiverWare™, is the core simulation tool, providing monthly and annual outputs of key variables, including reservoir storage, reservoir elevations, dam releases, and river flows. The simulation is based on a mass-balance calculation that accounts for water entering the system, water uses (diversions and consumptive use), water losses (evaporation), intervening gains and losses, and water movement through the system.

Input data for the model include monthly natural inflows, physical process parameters (e.g., evaporation rates for reservoirs), initial reservoir conditions, and future diversion and depletion schedules for the Basin States and for Mexico. The operating rules for the Colorado River system reservoirs (including Lake Powell and Lake Mead) are also considered inputs to the model. Detailed descriptions of CRSS and the hydrologic model process are included in **Appendix A**, CRSS Model Documentation.

Assumptions

In addition to the specific operating rules necessary to model each alternative (discussed in **Chapter 2** and the associated appendices) and the CCS Comparative Baseline, modeling of Colorado River system operations requires assumptions about various aspects of inflows, water delivery, and system operations that are common to all alternatives and the CCS Comparative Baseline. These assumptions include:

- **Input Data Consistency:** All simulations use a common set of input data to isolate the effects of alternative operational guidelines.
- **Hydrologic Variability:** Simulations use 400 different hydrologic traces to capture the variability inherent in natural flows.

- **Initial Conditions:** Three sets of 2027 reservoir elevations are used to capture the uncertainty in 2026 inflows and system starting conditions.
- **Future Water Demands:** Upper Basin depletion schedules were developed from the Upper Colorado River Commission's updated 2016 Depletion Demand Schedule (**Appendix L**, Upper Division Depletion Schedules). The modeled Upper Basin use varies due to hydrologic conditions and alternative specific conservation assumptions. Lower Basin depletion schedules were developed by Reclamation (**Appendix N**, Lower Division Depletion Schedules). Lower Basin depletion schedules start at full apportionment and modeled use varies by alternative specific shortage, surplus, and conservation assumptions.
- **Physical Process Parameters:** Assumptions regarding evaporation, bank storage, and other processes are based on the most current measurements and modeling studies.
- **Infrastructure Constraints:** At high and low reservoir elevations.

Detailed modeling assumptions and other aspects of the simulation are documented in **Appendix A**, CRSS Model Documentation. All results in **Chapter 3**, and the supporting technical appendices in **Volume III** are based on the single Upper Basin demand assumptions described above. **Appendix I**, Sensitivity Analysis – Effects of Alternate Upper Basin Demand Scenarios on Operations at Lake Powell and Lake Mead, presents a sensitivity analysis that evaluates how future Upper Basin demands assumptions influence modeled system conditions and vulnerabilities for select hydrologic and water delivery impact indicators.

3.2.5 Resource Model Description

In addition to CRSS, a suite of resource-specific models was used to evaluate potential effects of the alternatives on individual resource areas. These models build on CRSS outputs and provide finer-scale or specialized analyses tailored to individual resource areas. **Table 3-3** lists the primary models and the resources they support.

Table 3-3
Models and Supported Resources

Model/Owner	Primary Purpose	Resource Areas Supported
CRSS/RiverWare™ (Reclamation)	Core system operations model; simulates reservoir elevations, releases, river flows, and salinity.	Hydrologic Resources; Water Deliveries; Dams and Electrical Resources, Water Quality; Visual Resources; Vegetation; Terrestrial Wildlife
SAM / Alternative Distribution Model(s) (ADM) (Reclamation)	Emulates a distribution of Colorado River water shortage among entitlement holders under shortage tiers and allocation assumptions; translates tiers into volumes for specific users/jurisdictions.	Water Deliveries; Socioeconomics; Indian Trust Assets (ITAs); Lands and Population

Model/Owner	Primary Purpose	Resource Areas Supported
High-Flow Experiment (HFE) / Sediment models (Grand Canyon Monitoring and Research Center [GCMRC] / U.S. Geological Survey [USGS])	Simulates sediment transport and geomorphic response to HFEs (sand mobilization, sandbar building, channel budgets). Evaluates whether and how often HFEs rebuild sandbars.	Geomorphology/Sediment
CRSP Python model (CRiSPPy)/WAPA	An advanced hydropower scheduling tool that projects annual electricity production and powerplant firm capacity. The hourly release data generated by this model is used as an input for many of the GCMRC models listed below.	Dams and Electrical Power Resources
GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry and Grand Canyon (Reclamation/ GCMRC/USGS)	Evaluates thermal stratification, interflows, and downstream release water temperatures and dissolved oxygen conditions, especially important for aquatic resource (humpback chub, trout) impacts and selective withdrawal scenarios.	Water Quality; Fish and Aquatic
SNWA 3D Model and Machine Learning Models (SNWA)	Provides rapid statistical/machine learning forecasts (within training bounds) for temperature, total dissolved solids, and other water quality metrics.	Water Quality; Fish and Aquatic
Glen Canyon National Recreation Area (NRA) Exposed Shoreline Model (Lake Powell) (subaerially exposed sand model) (USGS/GCMRC/ Southwest Biological Science Center)	Predicts exposed sand and shoreline area as reservoir levels change; used to estimate aeolian sand availability and cultural/paleo exposure.	Air Quality; Cultural Resources; Paleontological Resources
Lake Mead Dust Model (USGS/GCMRC)	Predicts potential dust emissions from newly exposed shoreline and estimates human-health/air-quality impacts under drawdown scenarios.	Air Quality
Preservation Risk Model (USGS/GCMRC)	Ranks Lake Powell and Lake Mead (1–5) based on the potential for cultural and paleontological resource preservation to be affected by reservoir levels. Combines a resource distribution model with a preservation hazard model.	Cultural Resources; Paleontological Resources

Model/Owner	Primary Purpose	Resource Areas Supported
Joint Cultural/Paleo Models (Sand Area, Vegetation, and Sandbar Models) (USGS/GCMRC)	Integrates the aeolian sand availability model, vegetation habitat suitability model, and sandbar volume model. Together, these evaluate sand supply, vegetation cover, and sandbar dynamics as key drivers of cultural and paleontological resource preservation in the Grand Canyon.	Cultural Resources; Paleontological Resources
Smallmouth Bass Model (entrainment and population growth proxies) (GCMRC)	Estimates entrainment rates of smallmouth bass through Glen Canyon Dam, thermal suitability downstream, and consequent population establishment/growth (λ proxies).	Fish and Aquatic
(pending) Hydrologic Engineering Center's River Analysis System (HEC-RAS)	Simulates river hydraulics and floodplain inundation.	Vegetation; Terrestrial Wildlife; Fish and Aquatic
Whitewater and Angling Economic Model (USGS/GCMRC)	Estimates changes in recreation value (rafting in Grand Canyon, angling in Glen Canyon) under varying flow and condition scenarios.	Recreation
Socioeconomic IMPLAN (Impact Analysis for Planning) commercial regional input-output model	Assesses community-level socioeconomic outcomes (employment, income, tax base, social vulnerability) from water delivery and recreation/hydropower impacts. Converts changes in agricultural output (or other direct effects) into regional economic impacts.	Socioeconomics

Additional specialty models that further tier to the above models are introduced in their respective resource sections.

3.2.6 Decision Making under Deep Uncertainty

To help inform the impact analysis, a decision making under deep uncertainty (DMDU) approach, drawn from a well-established branch of decision science, was implemented to evaluate how each alternative performs across a wide range of plausible future hydrologic and operational conditions. As described in Smith et al (2020), this approach is appropriate because of extreme uncertainty in future hydrology, the inability to accurately assess the probability distribution of future inflows, and the desire to avoid overconfidence in probabilistic predictions that will vary depending on model inputs.

The DMDU approach is a non-probabilistic evaluation framework that compares alternatives based on their ability to meet specific performance criteria in many potential future conditions and how the alternatives respond to specific hydrologic conditions. Importantly, the DMDU approach does not assume the likelihood of any future conditions *before* the quantitative analysis is performed. Instead, it first evaluates a broad range of future conditions and then, *after the analysis is presented*, it provides the opportunity to consider whether specific impacts are reasonably foreseeable based on individual judgment about likely future conditions.

Additional background and technical details about the DMDU framework are provided in **Appendix E**, DMDU Overview and Approach.

Overview of the DMDU Analysis Framework

The key to successful DMDU-style analysis is structured model inputs that capture a range and variety of conditions related to the key factors that drive the uncertainties in the model outputs. For this EIS process, the most impactful uncertainty is future hydrology. Four hundred hydrology sequences (traces) were selected from a suite of data sources that include observed flows, reconstructions of historical flows based on tree ring analysis, statistical models that combine information about recent trends, historical patterns, and projected variability, and projections derived from climate models. The traces capture a wide range of potential future conditions and a variety of streamflow statistics. This ensures that the alternatives are thoroughly tested and enables targeted analysis to understand how each alternative responds to specific hydrologic conditions. Three sets of 2027 reservoir elevations (high, mid, and low) are also included to represent uncertainty in initial conditions. Each set of initial conditions is combined with the 400 different hydrology (streamflow) traces to generate a total of 1,200 futures. Each alternative is simulated in all 1,200 futures using the CRSS model and subsequent resource-specific models. For more information about the hydrology used in this analysis, refer to **Appendix F**, Approach to Hydrologic Uncertainty, and for more information on the initial reservoir condition used in the analysis, refer to **Appendix G**, CRSS Initial Conditions.

Overview of DMDU Figures and Terminology Included in this Analysis

Throughout the resource analysis there are three standard figures: conditional boxplots, robustness heatmaps, and vulnerability bar plots. Each type of figure explains key information regarding performance. When taken together, the figures provide a full picture of how the alternatives compare and whether significant negative impacts are reasonably foreseeable under each alternative. The following sections introduce these figures and provide annotated examples to assist with understanding the resource analysis.

DMDU enables readers to apply individual judgement about the likelihood of specific impacts: The quantitative analysis underpinning this document tests alternatives in a wide range of conditions to identify relationships between hydrologic conditions and system impacts. The DMDU-oriented figures can be combined with historical hydrologic context and future projections to understand whether impacts of concern are reasonably foreseeable. These connections will be demonstrated as each figure is introduced.

Conditional Boxplots

The conditional boxplot figures show how the alternatives respond to different categories of preceding hydrology and enable a comparison of alternatives in specific hydrologic conditions (e.g., average conditions or dry conditions). To create these figures, all 34 years (2027–2060) from all 1,200 simulated futures (40,800 data points per alternative) are separated into five categories based on their preceding 3-year average Lees Ferry natural flow.[4,5] Then, the resource outcomes for each year are sorted into their respective categories, resulting in a range of potential system outcomes that could occur given the preceding hydrologic conditions. The range of values is presented as a boxplot to summarize the statistical distribution of outcomes.

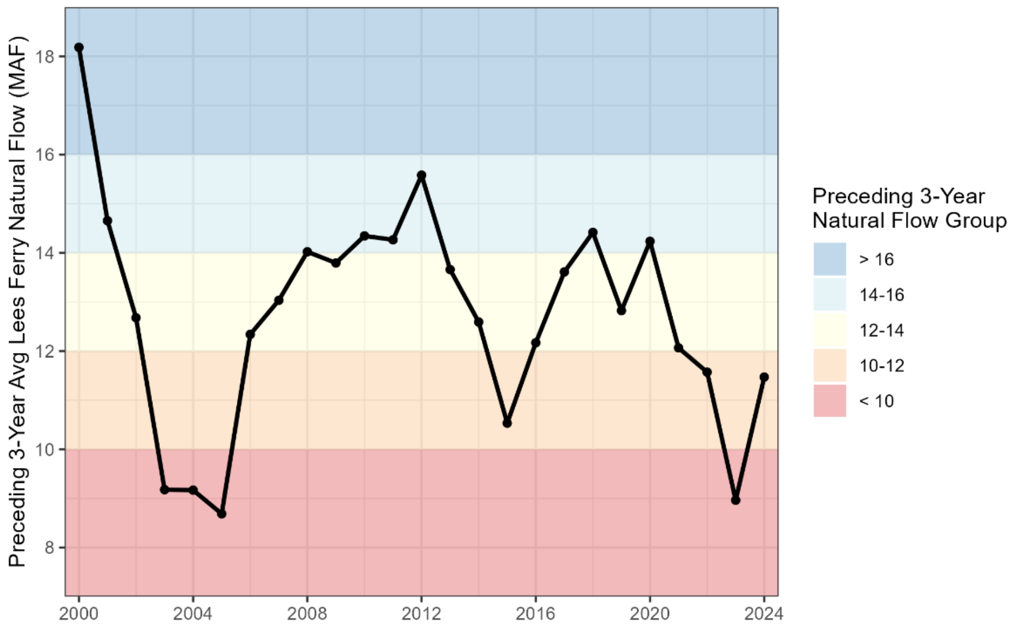
The flow categories were defined based on how they compare to historical conditions and stakeholders' understanding of different historical periods, as presented in **Table 3-4**, Colorado River Flow Categories. **Figure 3-1**, Preceding 3-Year Average Lees Ferry Natural Flow, 2000 to 2024, shows how the preceding 3-year average Lees Ferry natural flow varied from 2000 to 2024 and demonstrates the relevance of these categories in recent history.

Table 3-4
Colorado River Flow Categories

Flow Category Name	Range of Preceding 3-Year Average Lees Ferry Natural Flows (maf)	Percent of Modeled Years in Flow Category	Number of Observed Years in Flow Category, 2000–2024
Wet	16.0–31.11	17	1
Moderately Wet	14.0–16.0	20	7
Average	12.0–14.0	25	10
Dry	10.0–12.0	21	3
Critically Dry	4.46–10.0	17	4

[4] Natural flow at Lees Ferry is a calculated estimate of the flow at that point in the river undepleted by human activities upstream (e.g., reservoir evaporation and regulation, consumptive use). Given that over 90 percent of the total water in the system originates upstream of Lees Ferry, it is a good proxy for the amount of water available to the system overall. This makes it a useful way to categorize hydrology traces.
[5] The 3-year average is used because it is long enough to show impacts from multiple years of moderately challenging hydrology yet short enough to capture the impacts of annual extremes.

Figure 3-1
Preceding 3-Year Average Lees Ferry Natural Flow, 2000 to 2024



A sample conditional boxplot figure with annotations for guidance is provided in **Figure 3-2,** Sample Conditional Boxplot for WY Minimum Combined Storage of Lake Powell and Lake Mead. **Figure 3-2** has numbered annotations to describe the features of the figure and provide an example summary of what the figure shows about the comparison between the No Action Alternative and the CCS Comparative Baseline. Reading the text in numerical order will provide the clearest understanding.

Conditional boxplots in the impacts analysis will show these two operations alongside the action alternatives. Additionally, reference lines representing values of interest (e.g., historical values or critical thresholds) will be shown with dashed lines. Conditional boxplots will be accompanied by tables of values captured in the boxplots to ensure that precise statistics are communicated.

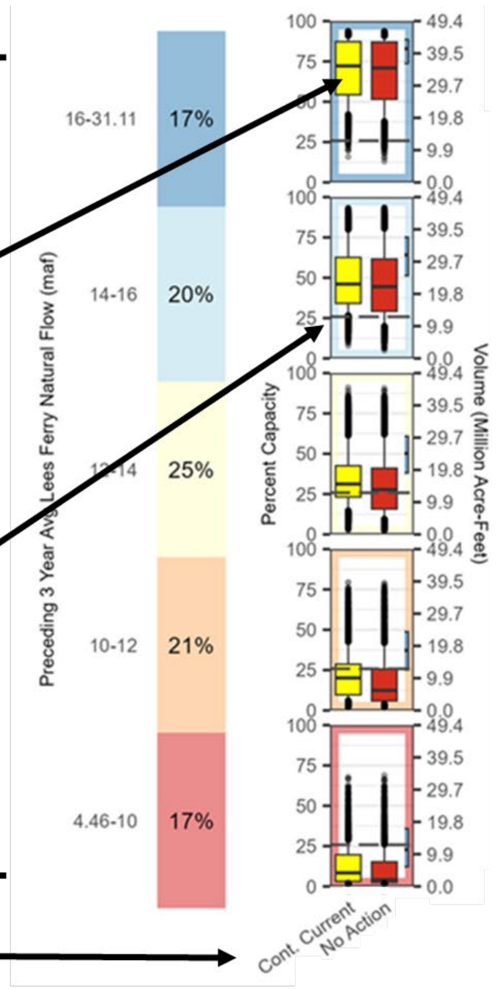
Figure 3-2
Sample Conditional Boxplot for WY Minimum Combined Storage of Lake Powell and Lake Mead

1. The flow categories are assigned a color and the amount of data in each category is provided as a percent.

3. Because there are many data points in each category, their distributions are presented as boxplots. See the boxplot legend in the bottom right of this page.

4. A reference line of 12.77 maf (25.84%), which is the minimum observed combined Lake Powell and Lake Mead storage since both reservoirs filled (observed in March 2023) is shown on each panel.

2. Each alternative and the CCS Comparative Baseline is represented by a colored boxplot.

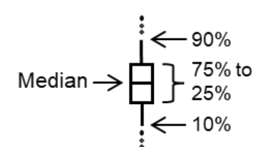


5. The No Action Alternative and CCS Comparative Baseline perform similarly when the preceding 3-year average annual flow was moderately wet or wet.

6. In the middle flow category, both operations have a significant number of years falling below the reference line, but the No Action Alternative performs worse, with almost 50% of years below the threshold.

7. The No Action Alternative continues to perform worse than the CCS Comparative Baseline in both the moderately dry and dry categories, but under the driest conditions the difference is small because both result in about 90% of years falling below the reference line.

Boxplot Legend: Percentages of Data



The connection between system outcomes and hydrologic conditions is clear in the conditional boxplots because the data is sorted by the preceding 3-year average hydrology. To determine which hydrologic categories to focus on and which impacts to contemplate as reasonably foreseeable, the recently observed conditions presented in **Figure 3-1** and **Table 3-4** offer useful context. The Average category is the most common since 2000, while the Wet category is the least common. There have been as many combined instances of Dry and Critically Dry conditions (seven) as there have been instances of Moderately Wet (though, notably, most of the Moderately Wet instances were close to being Average). Recent history combined with the increasing temperature trend, which is associated with lower streamflow, suggests that focusing more on the Average and Dry categories is warranted. However, Critically Dry conditions have been observed and could become more common.

Within each flow category, the distribution of data provides a connection to conditions that occurred before the 3 years used to sort the data into categories: the higher end of a distribution is likely the result of wetter conditions preceding the 3 years, and the lower end of a distribution is likely the result of drier conditions preceding the 3 years. Considering that 20 out of 24 years since 2000 have fallen in the Moderately Wet, Average, and Dry flow categories, it is prudent to focus on specific portions of the distribution within each flow category: the 25th to 75th percentiles (the colored portions of the boxes) are most relevant, since the high and low ends of the distributions are representative of extreme conditions occurring before the 3 years used to sort the data into the flow categories.

Robustness Heatmaps

A robust alternative is one that achieves a preferred level of performance under a wide range of future conditions. Robustness heatmaps show the alternatives' ability to meet different levels of performance over one or more decades in the wide range of potential future conditions used in the analysis. Since there are many ways to analyze performance for each resource, there are many opportunities to define meaningful levels of performance. A definition for a single level of performance requires three components: the modeled outcome of a system variable over a time period (i.e., a timeseries), a threshold, and a frequency of meeting the threshold over the specified period.

When a simulated (or modeled) future meets the specified level of performance, it is considered a "successful future." Under each alternative, the percentage of futures (out of 1,200 modeled futures) that are successful provides information about how robust the alternative is. A large percentage of successful futures (i.e., a high robustness score) means that the alternative is robust (i.e., it performs well) with respect to the specified level of performance; a low percentage of successful futures means that the alternative is not robust with respect to the specified level of performance.

The data that was sorted into categories for the conditional boxplots in **Figure 3-2** can be used in an example robustness heatmap. Performance levels are defined using the annual timeseries of minimum WY combined storage in Lake Powell and Lake Mead (i.e., the minimum storage recorded in each WY from 2027 through 2060) and comparing the timeseries to the threshold of the minimum observed storage (12.77 maf), where staying above this value is better. The final component of defining a level of performance is the frequency of staying above the minimum observed combined storage (100 percent of years, 90 percent of years, etc.).

Figure 3-3 compares the robustness of the No Action Alternative to the CCS Comparative Baseline with respect to their ability to maintain different levels of performance in combined Lake Powell and Lake Mead storage. It is annotated using numbered descriptions as a guide to the features of the figure and a summary of findings. Reading the text in numerical order will provide the clearest understanding.

In **Figure 3-3**, each row represents a different level of performance. This is useful because individuals can have different opinions about what level of performance is necessary for a given resource. In this case, they could focus on the row that best aligns with their preference. At the same time, it is useful for resource experts to identify a 'preferred minimum level of performance,' which is identified in **Figure 3-3** by the purple box. In this example, the preferred minimum performance level is for the combined storage of Lake Powell and Lake Mead to stay above 12.77 maf in at least 90 percent of years. The preferred minimum performance level is also the basis for vulnerability analysis, as described in the next section.

This type of figure is referred to as a "heatmap" because clusters of colors provide an easy way to identify regions of robustness or lack of robustness across the alternatives. Robustness heatmaps contain a large amount of information, but even a brief visual inspection can provide the key conclusions about robustness.

Key visual tips to quickly interpret robustness heatmaps: Every column of colors represents the robustness of an alternative across different levels of performance in a given resource. The more blue there is in a column, and the darker the blue, the more robust an alternative is; a large amount of orange or red, and especially dark red, means an alternative is not robust with respect to a specific type of performance.

For all modeling periods (the full modeling period and individual sub periods), approximately 75 percent of the 400 hydrology traces had an average annual flow lower than the 1906–2024 average of 14.6 maf.[6] Across all periods, approximately 50 percent of traces had an annual average flow lower than the 1988–2024 average, and more than 25 percent of traces had an average that is lower than the 2000–2024 average. Over the subperiods, the 25th percentiles, 10th percentiles, and the driest traces became drier.

[6] In the first subperiod (second panel from the left) the distribution is slightly higher at the median and 75th percentiles. This is a statistical artifact from several of the constituent ensembles, not a prediction that supply could increase between 2027 and 2039.

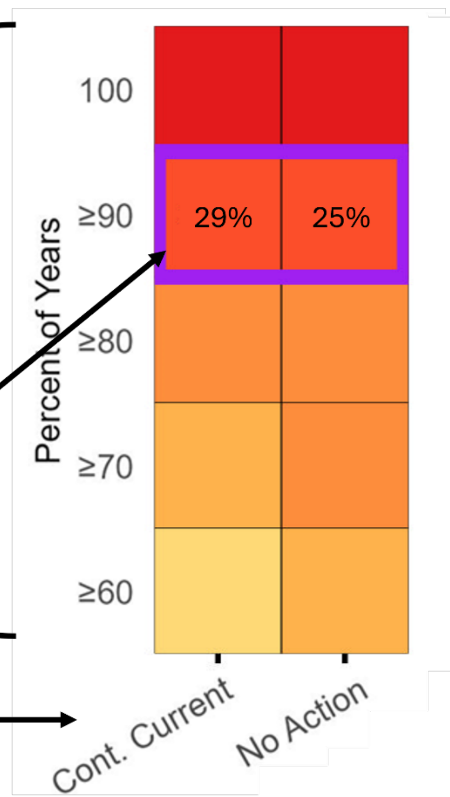
Figure 3-3
Sample Robustness Heatmap for WY Minimum Combined Storage of Lake Powell and Lake Mead.
Percent of futures in which the WY minimum combined storage stays above the historical minimum (12.77 maf) in the percent of years specified by each row

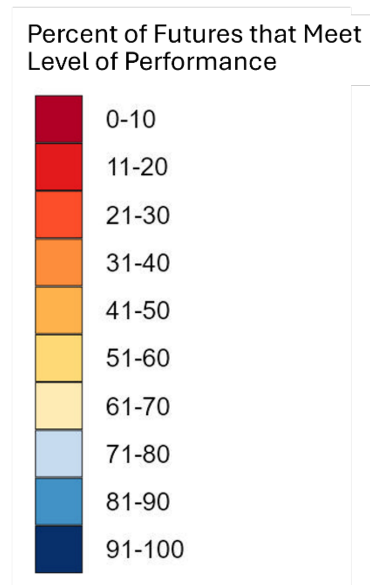
1. The subtitle describes the time-series, threshold, and frequency used to calculate robustness (i.e., the percentage of 1,200 futures that meet the performance requirement).

4. The rows in the heatmap capture different levels of performance. The highest row is the hardest level of performance to achieve (colors are more likely to be red, orange or yellow) and the lowest row is the easiest (colors are more likely to be blue). In this example, each row represents a frequency of keeping combined Lake Powell and Lake Mead storage above the observed minimum.

5. The purple highlighted row denotes a *preferred minimum performance*. This row is the focus for figure descriptions and is the performance level used in vulnerability bar plots.

2. Each alternative and the CCS Comparative Baseline has a column of “cells” that are colored based on the legend.





6. The ability of different alternatives to maintain a reasonable minimum amount of storage in Lake Powell and Lake Mead is an important consideration when evaluating their performance. Here, the observed minimum volume of 12.77 maf is taken as a significant threshold, and the preferred minimum performance is to stay above that threshold in at least 90% of years across the 34-year simulation period (purple outlined row). The CCS Comparative Baseline achieves this level of performance in 29% of futures, so it is slightly more robust than the No Action Alternative which only achieves it in 25% of futures. Both improve their robustness as the performance standard is lowered (looking down the rows), with CCS Comparative Baseline achieving above 50% robustness (light yellow cell) when the frequency of staying above the observed minimum storage is relaxed to 60% of years.

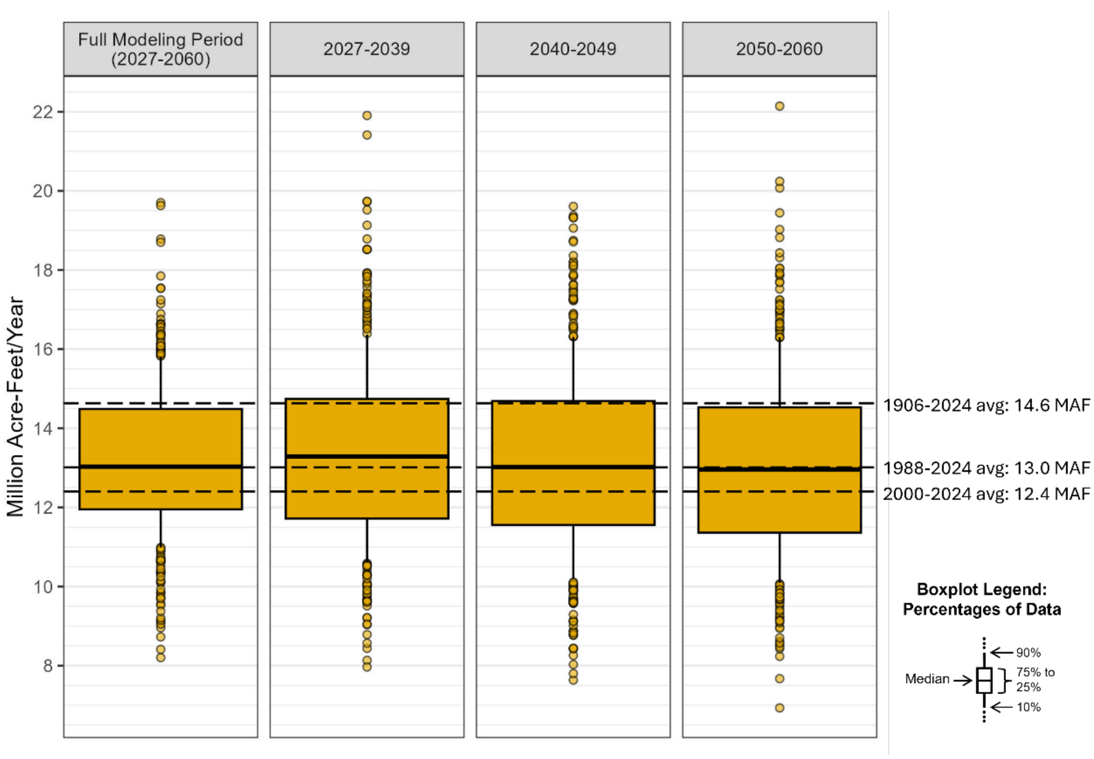
3. The colors in the legend indicate the percentage of futures out of 1,200 in which the performance standard in each row is met across the time period 2027 to 2060. Each cell in the heatmap has a color corresponding to the robustness of an alternative with respect to the performance standard in that row. Higher percentages (darker blues) indicate higher robustness.

The distributions of these statistics can be roughly mapped to robustness percentiles to understand the average conditions associated with unsuccessful futures. For example: over the full modeling period, if a resource is sensitive to drier conditions and an alternative has a robustness score of 90 percent, it is unsuccessful in 10 percent of futures and it is reasonable to map this unsuccessful percentage to the driest 10 percent of the average flows, meaning that the failures are most likely occurring in futures where the 34-year average flow is 11 maf or lower. Readers can determine whether these average conditions are reasonably likely to occur, in which case a 90 percent robustness score may not be adequate to avoid negative impacts on the resource. For resources that are sensitive to wet conditions, the higher end of the distribution of average flows should be referenced. Note that these comparisons are only approximations but are useful for providing context to robustness scores.

Assessing which alternatives are in shades of blue (generally robust) and which are in shades of yellow, orange, or red (generally not robust) for a given level of performance provides a basic level of information that is sufficient for comparison. To apply judgment about what robustness score is adequate, it is beneficial to understand the statistical distribution of the underlying hydrology.

Figure 3-4 shows annual average flows by trace for the full 400-trace hydrology ensemble over different time periods and compares them to historical averages.

Figure 3-4
Average Annual Lees Ferry Natural Flow by Trace for 400-Trace Hydrology Ensemble over Different Time Periods



Vulnerability Bar Plots

Vulnerability bar plots provide complementary analysis to the robustness heatmaps by identifying the specific hydrologic conditions in which each alternative is likely to succeed or fail the preferred minimum performance level[7] (recall, the preferred minimum performance is shown by the purple-outlined row of the heatmap). For example, the heatmap in **Figure 3-3** shows that the CCS Comparative Baseline successfully meets the preferred minimum performance level in 29 percent of futures, meaning that the CCS Comparative Baseline is unsuccessful in the remainder of the futures (71 percent of futures). Vulnerability analysis uses information about both the successful and the unsuccessful futures to identify hydrologic conditions (via statistical characteristics) that are most skillful at predicting the different outcomes. Examples of the types of hydrologic statistical characteristics tested are:

- the driest 20-year average Lees Ferry flow over a 34-year hydrology trace
- the driest 10-year average Lees Ferry flow over a 34-year hydrology trace
- the median 10-year average Lees Ferry flow over a 34-year hydrology trace

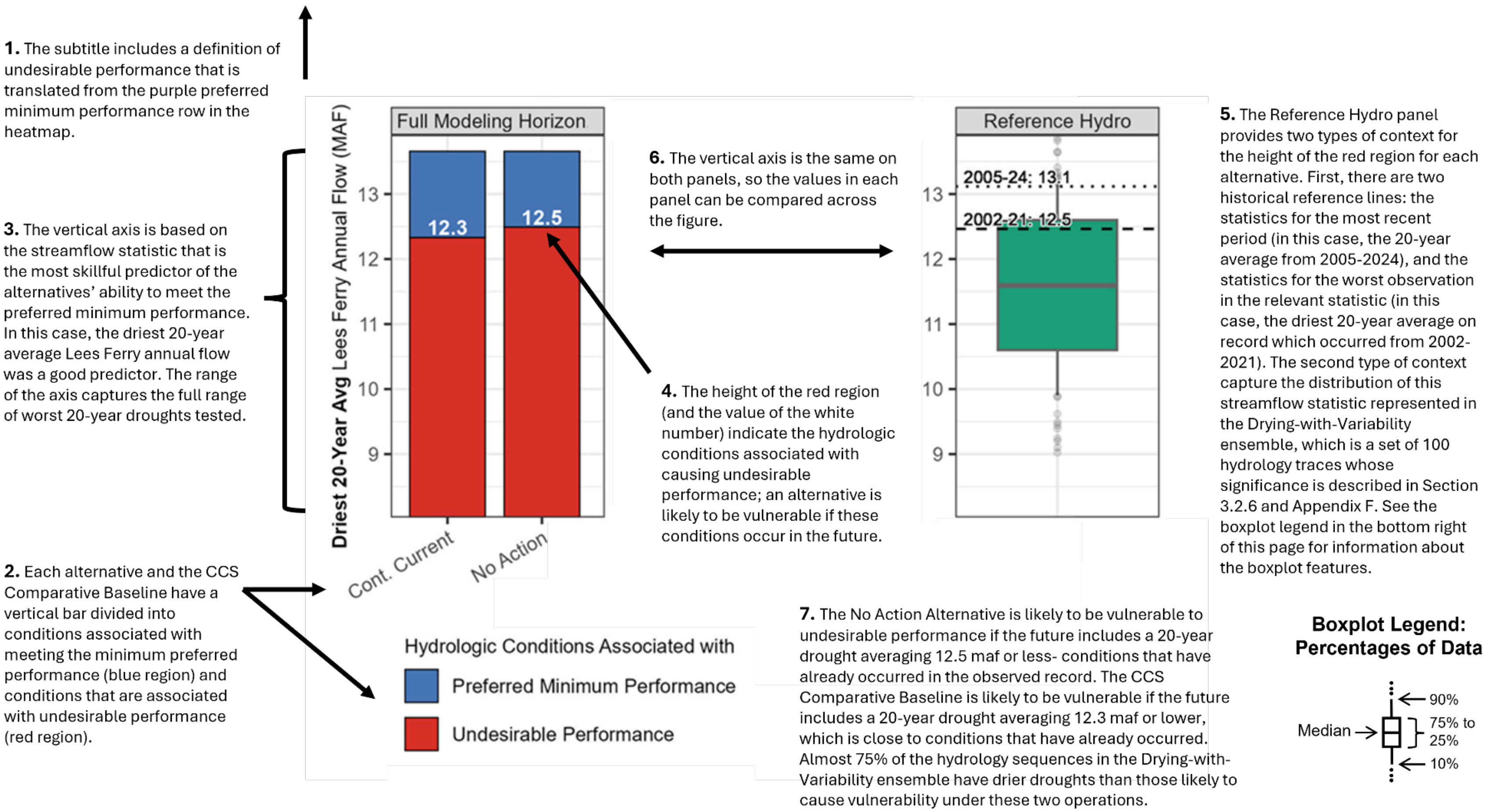
The first two examples are the hydrologic characteristics generally found to be the most skillful predictors because they are highly correlated with the undesirable resource outcomes that occur due to dry hydrology. For information about other predictors and how they are tested, refer to **Appendix E**, DMDU Overview and Approach.

Once a skillful predictor is identified, the alternatives can be described in terms of the hydrology conditions associated with undesirable performance (i.e., the conditions in which an alternative is vulnerable). Alternatives will have different vulnerabilities because of their different approaches to operating the reservoirs. Conditions associated with vulnerability can then be compared to conditions that have occurred in the past and a range of conditions that could potentially occur in the future; if conditions that have already occurred are similar to those associated with vulnerability under an alternative, the conclusion is that the undesirable impacts are reasonably likely to occur in the future.

Figure 3-5 compares the vulnerability of the No Action Alternative and the CCS Comparative Baseline with respect to avoiding undesirable performance in combined Lake Powell and Lake Mead storage (i.e., falling below the historical minimum in more than 10 percent of years). The figure also shows how each alternative's vulnerability compares to conditions that have occurred in the past or could potentially occur in the future. It is annotated using numbered descriptions as a guide to the features of the figure and a summary of findings. Reading the text in numerical order will provide the clearest understanding.

[7] Vulnerability analysis considers if the performance levels are violated any time during the 34-year modeling period. Using the full modeling is preferred such that one hydrology statistic can accurately predict if an alternative will meet the performance level. A decadal-based analysis (like what is included in some robustness heatmaps) would require a multi-dimensional prediction accounting for reservoir storage at the start of each decade, which varies by alternative and hydrology, making it difficult to compare alternatives.

Figure 3-5
Sample Vulnerability Bar Plot for WY Minimum Combined Storage of Lake Powell and Lake Mead. Conditions that could cause Combined Lake Powell and Lake Mead storage to fall below the historical minimum in more than 10 percent of years



Vulnerability bar plots capture complex information, but even a brief visual inspection can provide the key conclusions about whether undesirable impacts could be reasonably expected under a given alternative.

Key visual tips to quickly interpret vulnerability bar plots: Every alternative is linked to a bar that is divided into blue and red; the larger the red portion, the wider the range of hydrology conditions in which the alternative is vulnerable. If the red portion of the bar encompasses, or is close to, conditions that have already occurred according to the reference hydrology panel, undesirable performance in that resource is likely to occur. (If a bar is completely blue, none of the conditions tested caused vulnerability and the alternative is robust.)

The "reference hydrology" panel introduced in **Figure 3-5** is included in every vulnerability bar plot to provide context for interpreting the likelihood of the conditions associated with vulnerability. The historical reference lines are the first component of the context, and anytime an alternative is vulnerable to conditions that have already been observed, it is reasonable to assume these conditions can occur again.

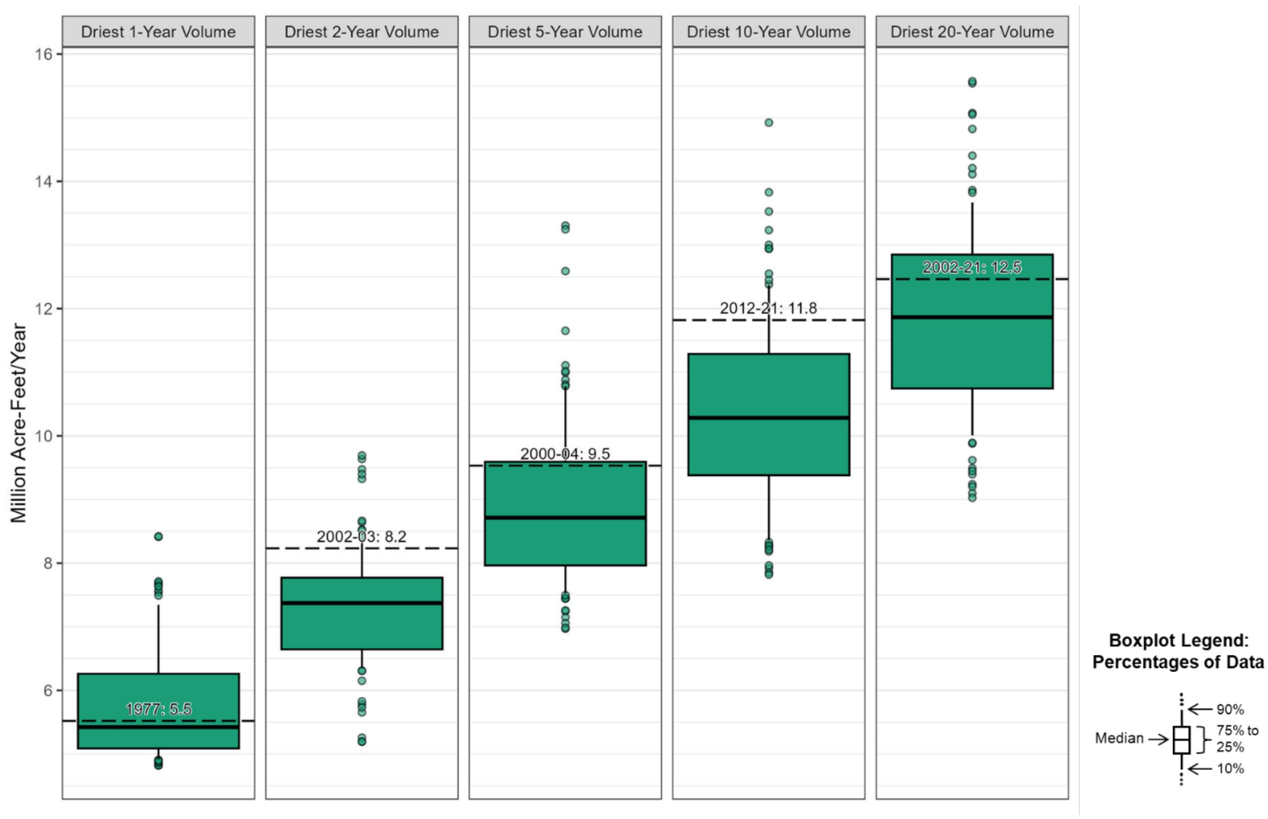
The second component of the context is the boxplot that shows projections about potential future conditions. These projections are based on the "Drying-with-Variability" ensemble, which is a 100-trace statistically generated ensemble that represents conditions that may occur in the future.[8] Long-term planning in the Basin must consider the significant potential for a future with more frequent, sustained, and/or severe dry periods and a downward trend in average flows, but this does not preclude the occurrence of wet years. The Drying-with-Variability ensemble was designed to capture this by combining information about the observed temperature trend, temperature's impact on the translation of precipitation into streamflow, and the sequencing of wet and dry periods from paleo reconstructed data while preserving the potential for infrequent but significant wet years.

Figure 3-6 shows key statistics for the Drying-with-Variability ensemble. Because dry conditions are of the greatest concern given recent trends and critically low reservoir storage, the figure and discussion are focused on statistics related to the dry.

Figure 3-6 provides the distribution of statistics across the 100 traces in the ensemble and compares them to the worst statistic in the observed record (1906–2024). For the driest 1-year flow, over 50 percent of Drying-with-Variability traces have a drier year than the lowest observed flow, with the lowest single-year flow in the ensemble falling below 5 maf. In the 2-to-10-year windows, 60 percent of traces or more are drier than the worst observed statistic; for the driest 10-year volume, approximately 85 percent of traces contain drier decades than the worst observed decade, which occurred from 2012 to 2021.

[8] For additional information about this ensemble, refer to **Appendix F**, Approach to Hydrologic Uncertainty.

Figure 3-6
Key Statistics for the Drying with Variability Ensemble



The purpose of describing the narrative, underlying data, and statistics of the Drying-with-Variability ensemble in the introduction to DMDU figures is to highlight that vulnerability bar plots provide a large amount of information that allows readers to use their judgment in determining the likelihood of negative resource impacts. The vulnerability bar plots combine information about the conditions in which each alternative is vulnerable, historical context, and the potential for a drier future.

3.2.7 Salton Sea

During scoping, Reclamation received comments requesting analysis of impacts on the Salton Sea. The Salton Sea is a terminal lake in Riverside and Imperial Counties, California. Salton Sea elevations are influenced by runoff from the surrounding Imperial Valley and Coachella Valley watersheds, as well as agricultural drainage from the IID and CVWD. As explained below, analysis of impacts on the Salton Sea is not included in this EIS.

The Salton Sea acts as a terminal sump for agricultural drainage; therefore, reductions in agricultural runoff could impact Salton Sea elevations, which, in turn, could impact air quality and shoreline wildlife habitat. Agriculture in the IID and CVWD service areas, as well as smaller non-agricultural uses, are sustained by Colorado River water diverted at the Imperial Dam and delivered via the All American and Coachella Canals. In recent years, total diversions of Colorado River water were approximately 2.8 maf per year at the Imperial Dam (California Natural Resources Agency 2024).

Over the past 20 years, inflows to the Salton Sea have declined from 1.3 maf per year to approximately 1.1 maf per year (California Natural Resources Agency 2024), primarily related to California's reduced usage of Colorado River water due to the prolonged drought in the Basin and changing agricultural practices, including implementation of water conservation programs.

The California Natural Resources Agency established the Salton Sea Management Program (SSMP) to oversee restoration efforts at the Salton Sea. Currently, the SSMP is working with local, state, tribal, and federal partners to implement the first phase of habitat restoration projects to establish at least 14,900 acres of aquatic habitat and up to 14,900 acres of vegetated habitat by the year 2028 (USACE 2024). Additionally, the SSMP released a long-range plan to address future recession of the Salton Sea beyond the year 2028 (California Natural Resources Agency 2024). The goal of the plan is to protect or improve air quality, water quality, and wildlife habitat to prevent or reduce health and environmental consequences anticipated from the long-term recession of the Salton Sea shoreline (California Natural Resources Agency 2024).

Given that inflows into the Salton Sea depend on a highly managed system, subject to growing water demands, and uncertain weather patterns and water polices, the SSMP used a range of projected annual net inflows to the Salton Sea: (1) high probability of inflow at 889,000 af, (2) low probability inflow at 684,000 af, and (3) very low probability at 444,000 af. These flows are used to project the future baseline of the Salton Sea and the restoration needs. The SSMP's long-range plan specifically acknowledges the uncertainty around policy decisions on this Colorado River Post-2026 process and is a reason for using a range of net inflows.

The SSMP's long-range plan is informing the scope of the Imperial Streams and Salton Sea Ecosystem Restoration Feasibility Study and NEPA compliance that the USACE is currently preparing. Once that process is complete, state and federal funding will be pursued to support the resultant design and construction of restoration projects, beginning around 2028.

For this Post-2026 process, Reclamation's action is to develop operational guidelines for the storage and release of water through Lake Powell at Glen Canyon Dam and Lake Mead at Hoover Dam. Reclamation's contracts with IID and CVWD do not provide Reclamation with the discretion to determine how individual water users within these districts use or allocate their water resources, including user decisions to participate or not participate in conservation programs.

Any reductions of Colorado River water available for diversion at the Imperial Dam for use by IID and CVWD could result in less available water for agriculture and, depending on the conservation activity or how the reduction would be implemented, subsequent drainage to the Salton Sea. While Reclamation cannot control Basin hydrology, there could be policy decisions that result in shortages. The alternative that would result in the largest possible shortage for IID and CVWD would be the Enhanced Coordination Alternative, with a maximum shortage of 3.0 maf, which is modeled as being distributed pro rata. A pro rata distribution under this alternative would result in a hypothetical maximum shortage to IID and CVWD of about 925,930 af for a minimum diversion amount from Imperial Dam of about 1.8 maf. Under this scenario, the resultant inflow to the Salton Sea would be about 783,000 af, which is within the range used by the SSMP long-range plan.

In summary, analysis of impacts on the Salton Sea are not included in this EIS for the following reasons:

1. Any resultant impacts are within the scope and range of inflows being considered in the SSMP's long-range plan and the USACE's ongoing NEPA process. While any resultant impacts on the Salton Sea may be accelerated by Post-2026 policies, the overall magnitude of impacts would not change.
2. Reclamation does not control the end use and management of delivered or conserved water. As such, Reclamation has no management authority over inputs to the Salton Sea, and Reclamation has no enforcement authorities over the Salton Sea. The State of California, IID, and CVWD have their own authorities not controlled by Reclamation. Reclamation would need new authorities and compliance to implement any policies that change how water shortages are distributed to IID and CVWD.[9]

3.3 Hydrologic Resources

3.3.1 Affected Environment

Overview and Study Area

This section summarizes the Basin's hydrology from the full pool elevation of Lake Powell to the SIB with Mexico. It also includes groundwater under direct influence of the Colorado River and the Lower Basin reservoirs. For a more detailed account of the affected environment for the hydrologic resources, please see **TA 3.1**, Hydrologic Resources.

Key Drivers and Trends

Worsening drought conditions have been a major driver for changes to hydrologic resources in the Basin. Since 2000, the Basin has experienced persistent drought conditions, exacerbated by higher temperatures, resulting in increased evapotranspiration, reduced soil moisture, and ultimately reduced runoff (Lukas and Payton 2020). The flow in the Colorado River is highly variable from year to year because of variations in precipitation in the Basin. However, the Basin is currently experiencing a prolonged period of drought; 2000 to 2024 was the driest 25-year period in more than a century. A paleo reconstruction of Colorado River streamflow at Lee Ferry, Arizona, back to 762 current era indicates that the recent 25-year period has lower streamflow than any other period in the last 1,200 years (Meko et al. 2007). These conditions have led to a cumulative streamflow deficit of about 70.0 maf relative to twentieth-century conditions (Reclamation 2025b).

Operational Impacts

The overall characteristics and connectivity of the Basin remain unchanged from when the 2007 Final EIS was issued. However, since 2007, key operational changes have affected hydrologic resources. Domestic agreements specifying such operations include the 2007 Interim Guidelines (supplemented in 2024), 2016 Glen Canyon Dam LTEMP (supplemented in 2024), and the 2019

[9] Reclamation's potential contribution of funds through contribution agreements does not affect the enforcement mechanisms of those state and local authorities.

DCP. More details on operational changes since 2007 can be found in **Section 1.8.2.1**, The Law of the River.

Reservoirs and River Reaches Overview

Upper Basin – CRSP Upper Initial Units

The 1956 CRSPA created four major Upper Basin reservoirs to support Colorado River Compact compliance: Flaming Gorge in Utah, Navajo in New Mexico, Blue Mesa in Colorado, and Lake Powell in Utah and Arizona. The CRSP Upper Initial Unit reservoirs include Flaming Gorge, Navajo, and Blume Mesa. Total live storage volume of the CRSP Upper Initial Units is 6.15 maf. Prolonged drought and low runoff conditions prompted the 2019 DROA (a component of the 2019 DCP) to allow strategic releases from the CRSP Upper Initial Units reservoirs to protect elevations at Lake Powell. As described in Section 3.2.1, operations at the CRSP Upper Initial Units specifically contemplated in the Draft EIS alternatives are intended to remain within the scope of the existing RODs. Accordingly, the Draft EIS does not expand the geographic scope of analysis upstream of Lake Powell.

Lake Powell and Glen Canyon Dam

Lake Powell is a reservoir located in southern Utah and northern Arizona. The water surface operating range of Lake Powell is between 3,490 feet (corresponding to the minimum power pool) and 3,700 feet (corresponding to the top of Glen Canyon Dam spillway). The total live storage capacity of Lake Powell at the full pool elevation of 3,700 feet is 23.31 maf (excluding 1.9 maf of flood control space). Due to persistent drought, storage levels in Lake Powell have declined, particularly in the early 2000s and from 2022 to 2023, when elevations were at an all-time low since filling. Should elevations drop below 3,490 feet, routine operations of Glen Canyon Dam would be discontinued, and hydropower can no longer be produced. Releases can still be made via the river outlet works down to elevation 3,370 feet (corresponding to dead pool), at which point water can no longer be delivered downstream. However, the outlet works are not designed nor intended for long-term use at low reservoir levels (Reclamation 2024a).

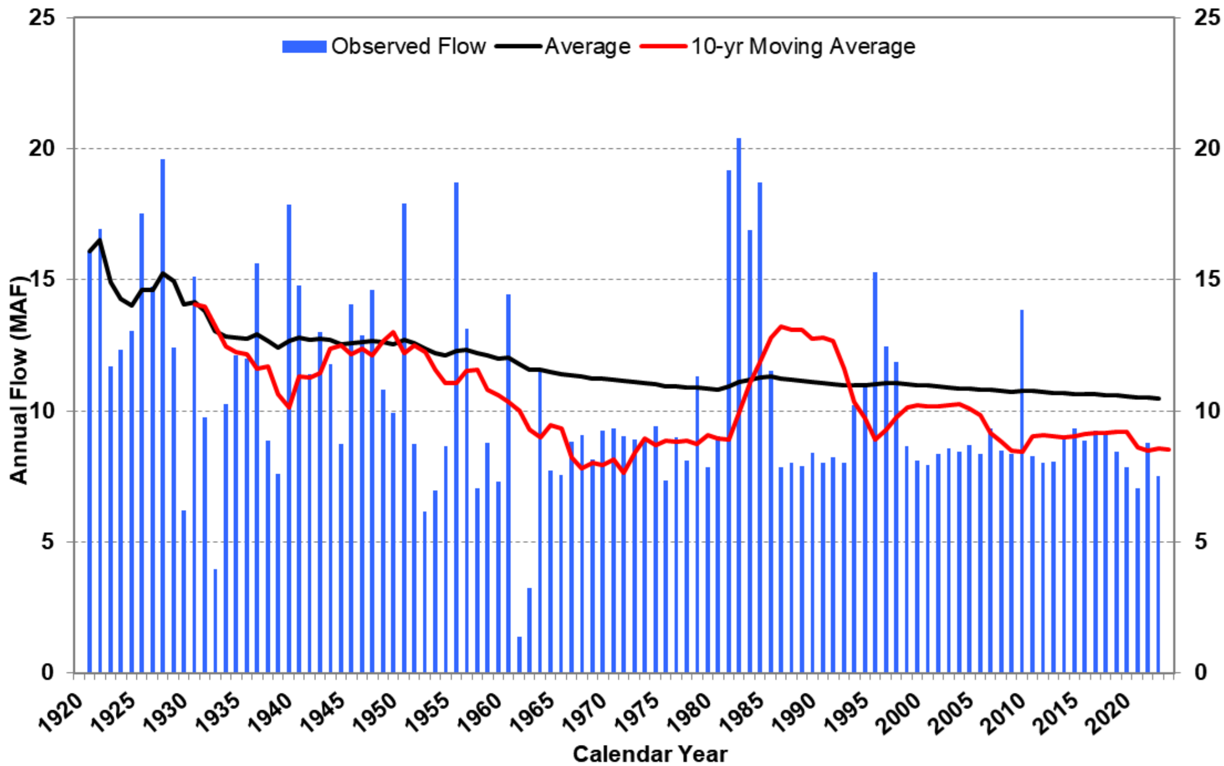
Unregulated inflows to Lake Powell from the Upper Basin vary year to year based on hydrologic conditions. A period of drought that began in 2000, exacerbated by increasing temperatures, has led to a 20 percent decrease in average annual Upper Basin (at Lee Ferry) natural flows (Reclamation 2025a). This continued dry period and decrease in inflows in recent years have resulted in Lake Powell approaching critically low elevations. Drought conditions from 2020 to 2022 triggered the need to supplement the 2007 Interim Guidelines with near-term provisions for addressing extremely low reservoir levels. The result was the 2024 ROD, providing for lower releases from Lake Powell. Since the implementation of the 2007 Interim Guidelines, the water surface operating range of Lake Powell has been between a low of 3,519.92 feet (occurring in 2023), and a high of 3,660.9 feet (occurring in 2011). Historical low and high elevations in Lake Powell are shown in **Figure TA 3-1** in **TA 3**, Hydrologic Resources. Annual Glen Canyon Dam releases from Lake Powell averaged 9.75 maf from 1996 through 2007, but have since averaged 8.69 maf (ranging from 7.00 maf to 12.52 maf from 2008 through 2024).

Lees Ferry Gaging Station and Lee Ferry Compact Point

The Lees Ferry Gaging Station is located in Arizona, approximately 15.9 RMs downstream of Glen Canyon Dam. This differs from the Lee Ferry Compact Point, which is the division point between the Upper Basin and Lower Basin as established by the 1922 Colorado River Compact. The Lee Ferry Compact Point is located a few miles downstream of the Lees Ferry Gaging Station.

Prior to the implementation of the 2007 ROD, the annual observed flow at Lees Ferry ranged from 1.4 maf (shortly after Glen Canyon Dam was built in 1963) to 20.4 maf (in 1984), with an average of 9.8 maf. Since the implementation of the 2007 ROD (2008 to 2024), the annual observed flows at the Lees Ferry Gaging Station have generally decreased. Annual observed flows have ranged from 7.0 maf (in 2022) to 13.9 maf (in 2011), averaging 8.8 maf. **Figure 3-7** below shows the observed flows recorded at the Lees Ferry Gaging Station for 1922 through 2024.

Figure 3-7
Colorado River Observed Flow at Lees Ferry Gaging Station, Arizona (1922–2024)



Source: Reclamation 2025c

Natural flows at Lees Ferry Gaging Station are calculated based on observed (gage) flow and corrected by Reclamation for upstream reservoir changes in storage and release, losses including evaporation, and depletions due to agriculture and domestic uses. **Figure TA 3-3** in **TA 3**, Hydrologic Resources, shows the historical natural flows at Lees Ferry Gaging Station.

Lake Mead, Lake Mohave, Lake Havasu, Cibola Gage, Imperial Dam, Northerly and Southerly International Boundaries

Approximately 292 miles downstream of Glen Canyon Dam is Lake Mead, formed by Hoover Dam. This reach of the Colorado River includes the Grand Canyon, which is approximately 277 miles long. Flows in this reach primarily consist of controlled releases from Glen Canyon Dam but do include minor contributions from perennial tributaries. The two largest tributaries in this reach are the Paria River and the Little Colorado River, which make up approximately 3 percent of the total flows in the Colorado River in this reach (USGS 2025a).

Lake Mead is located in Black Canyon, on both sides of the Arizona-Nevada state line near Las Vegas. The water surface elevation operating range for Lake Mead is between 895 feet (corresponding to dead pool) and 1,229 feet (corresponding to the top of the Hoover Dam spillway). The total live storage capacity of Lake Mead at the full pool elevation of 1,219.6 feet is 26.12 maf (excluding approximately 1.5 maf of flood control storage available above the maximum operating elevation). Low water level releases (below elevation 950 feet to elevation 895 feet) would continue through the four intake towers and penstocks, but would no longer be able to be released through the hydropower turbines; instead, below 950 feet, water would only be released through the river outlet works. When elevations drop below 895 feet (referred to as dead pool), water can no longer be delivered downstream from Hoover Dam.

Since 2007, water surface elevations at Lake Mead have generally declined. Since the implementation of the 2007 Interim Guidelines, the water surface operating range of Lake Mead has been between a low of 1,040.5 feet (occurring in 2022) and a high of 1,134.6 feet (occurring in 2012). Historical low and high elevations in Lake Mead are shown in **Figure TA 3-5** in **TA 3**, Hydrologic Resources. Annual Hoover Dam releases from Lake Mead ranged from 8.275 maf to 12.781 maf (averaging 10.199 maf) from 1996 through 2007, but have since ranged from 8.515 maf to 9.615 maf (averaging 9.185 maf) from 2008 through 2024.

Sixty-seven miles downstream of Hoover Dam is Lake Mohave, formed by Davis Dam. Lake Mohave is located on both sides of the Arizona-Nevada state line near Bullhead City, Arizona. Flows in this reach, from Hoover Dam to Lake Mohave, primarily consist of controlled releases from Hoover Dam; contributions from small tributaries make up less than 1 percent of the total flows (Reclamation 2007a). The average storage in Lake Mohave has remained constant, at approximately 1.6 maf over the past few decades. Lake Mohave is operated under an existing rule curve that determines specific target elevations at the end of each month. This rule curve was not affected by the 2007 Interim Guidelines, so the water surface elevation range at Lake Mohave stayed between approximately 630 feet to 645.7 feet, with an average of 640.9 feet since 2008.

Eighty-four miles downstream of Davis Dam is Lake Havasu, formed by Parker Dam. Lake Havasu is located on both sides of the California-Arizona state line near Lake Havasu City, Arizona. Flows in this reach primarily consist of controlled releases from Davis Dam, although contributions from the Bill Williams River make up approximately 1 percent of the total flows (USGS 2025b). Lake Havasu provides a forebay and desilting basin that pumps water for delivery to the MWD and CAP service areas. Similar to Lake Mohave, Lake Havasu is operated under an existing rule curve that determines specific target elevations at the end of each month. This rule curve was not changed by the 2007 Interim Guidelines and maintains Lake Havasu's water surface elevation between 445 and 450 feet. While the 2007 Interim Guidelines did not explicitly target Parker Dam operations, decreased inflows to Lake Havasu (as a result of decreased releases from upstream Lake Powell and Lake Mead) have resulted in decreased annual release rates. Since the implementation of the 2007 Interim Guidelines, the average annual releases from Parker Dam have decreased by 1.0 maf.

One hundred five miles downstream of Parker Dam is Reclamation's Cibola Gage. Flows in this reach primarily consist of controlled releases from Parker Dam. Decreased releases from Parker Dam in the last 20 years have resulted in decreased flows in this 105-mile reach. Two major diversion dams located in this reach are Headgate Rock Dam and Palo Verde Diversion Dam. The impoundments of these dams facilitate the diversion of water for the Colorado River Indian Tribes and the Palo Verde Irrigation District. Current operations keep these reservoirs at constant elevations. Thirty-eight miles downstream from the Cibola Gage is Imperial Reservoir, formed by Imperial Dam. Flows in this reach primarily comprise releases from Parker Dam. Imperial Dam was constructed to raise the water surface elevation enough to provide gravity-controlled flow to meet water deliveries to California via the AAC and to Arizona via the Gila Main Canal. The AAC diverts water for the IID, the CVWD, the Yuma Project, and the City of Yuma. The Gila Gravity Main Canal diverts water for Gila Valley, Yuma Mesa, and the Wellton-Mohawk area. Imperial Dam also regulates deliveries to Mexico.

Five miles downstream of Imperial Dam is Laguna Dam. Originally, Laguna Dam diverted water to the Yuma Project area but then the Imperial Dam was built. The Laguna Dam is now used as a regulating structure for sluicing flows from Imperial Dam and also provides downstream toe protection for Imperial Dam. Flows in this reach primarily consist of releases from Imperial Dam and contributions from the Gila River. Twenty-six miles downstream of Imperial Dam is the NIB between the U.S. and Mexico.

The Morelos Diversion Dam is 1.1 miles downstream of the NIB and impounds the majority of the water supply that is diverted by Mexico into the Reforma Canal. The dam is owned, operated, and maintained by Mexico per the 1944 Water Treaty. To ensure the annual 1.5 maf water delivery under Normal Conditions per the 1944 Water Treaty, the Morelos Diversion Dam operations have not changed as a result of the 2007 ROD. Refer to **Appendix M**, International Border Region of the Colorado River, for more details related to previous binational coordination efforts. Since most of the water is diverted at Morelos Diversion Dam into the Reforma Canal, flows in the Colorado River limitrophe downstream of Morelos Diversion Dam are infrequent. Flows downstream of Morelos Diversion Dam in the limitrophe to the SIB only occur due to Flood Control operations at Hoover Dam, seepage from Morelos Diversion Dam, irrigation return flows, groundwater inflow, and any water released for environmental purposes in the Colorado River Delta. The upper portion of the limitrophe is a gaining reach due to high groundwater levels in adjacent irrigated fields; however, in the southern portions of the limitrophe, groundwater elevations decrease, and it becomes a losing reach.

3.3.2 Environmental Consequences

This section provides a summary of the potential impacts on hydrologic resources for the No Action Alternative, four action alternatives, and (CCS Comparative Baseline. For a more detailed account of the environmental consequences for hydrologic resources, please see **TA 3.1,** Hydrologic Resources**.**

Methodology

The CRSS model was used to simulate Basin conditions and account for hydrologic uncertainty through the full analysis period (2060) on a monthly time-step. Reservoir elevations, reservoir releases, and river flows are outputs to the model and are used directly for the results presented in this resource section. To help visualize the different states of modeled futures, results from CRSS are framed using five potential flow condition categories that range from wet hydrologic conditions to dry hydrologic conditions. For background and guidance related to figures used in the analysis below (conditional boxplots, robustness heatmaps, and vulnerability bar plots), see **Section 3.2**, Analysis Methods.

Impact Analysis Area

The geographic scope of the hydrologic resources analysis is the Colorado River corridor from the upstream limits of full pool elevation of Lake Powell to the downstream limits of the SIB. Reservoirs upstream of Lake Powell are operated pursuant to their own RODs, which are not altered by the proposed alternatives.

Assumptions

The hydrologic resources results are direct outputs from the CRSS model. Refer to **Appendix A**, CRSS Model Documentation, for more details related to model assumptions and documentation. All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell and/or Lake Mead (refer to **Chapter 2 Sections 2.6–2.8** for a description of alternatives). Unless otherwise specified, impacts reflect modeling assumptions about voluntary conservation behavior.

Impact Indicators

Five impact indicators were used to assess impacts on hydrologic resources due to operational activities: reservoir elevations, system storage, reservoir releases, river flows, and qualitative impacts on groundwater adjacent to reservoirs and river reaches.

Issue 1: Reservoir Elevation

Water surface elevations at Lake Powell and Lake Mead are anticipated to be affected by the various alternatives as a result of changes to operational activities. Water surface elevations at Lake Mohave and Lake Havasu are not anticipated to be affected. The impacts on water surface elevations at each reservoir are summarized below. Refer to **Section TA 3.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources, for details regarding impacts on water surface elevations at Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu.

Lake Powell Reservoir Elevations

Refer to **Table TA 3-2** in **TA 3** for a list of critical elevations at Lake Powell. A statistical breakdown of CRSS modeling results for end of water year (EOWY) elevations and minimum WY elevations at Lake Powell can be found in **Table TA 3-3** and **Table TA 3-4** in **TA 3**, respectively.

Figure 3-8 below looks at the response of Lake Powell WY minimum elevations, and EOWY elevations and storage volumes to different hydrologic conditions under different alternatives by looking at the preceding 3-year average of Lees Ferry natural flow. The figure visualizes the same data that is included in **Table TA 3-3** and **Table TA 3-4** in two side by side conditional box plot panels. The bold center line of each box represents the median value, the top and bottom of each box capture the 25th to 75th percentile of the modeled results, the lines extend to the 10th and 90th percentiles, and the outliers are represented as dots beyond these lines. In each flow category shown in the box plots, the key elevations of 3,525 feet and 3,500 feet are identified with dashed lines. These elevations are important because they provide a 35-foot and 10-foot buffer, respectively, from 3,490 feet, the elevation below which water can only be released through the outlet works, constraining both the volume of water that can be released as well as the ability to generate power.

The alternatives and CCS Comparative Baseline generally perform similarly under potential hydrologic futures that are wet, except for the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), which have lower and more variable ranges of elevations. As potential hydrologic futures become drier, modeled water surface elevations at Lake Powell decrease under all alternatives, and differences between alternatives become more apparent.

In the Critically Dry Flow Category (4.46–10.0 maf), the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative are the only two alternatives with interquartile elevations that stay above the critical elevation threshold of 3,500 feet. The Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative have the highest and second highest EOWY median reservoir elevations, at 3,565 feet and 3,549 feet, respectively. For these alternatives, the EOWY median and interquartile elevations stay notably above the critical buffer threshold elevation of 3,500 feet. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) has median reservoir elevations that drop to 3,500 feet in the driest set of hydrologic futures. Median EOWY elevations shift below this critical threshold of 3,500 feet for the Basic Coordination Alternative (3,486 feet), the No Action Alternative (3,475 feet), and the CCS Comparative Baseline (3,498 feet).

For the WY minimum elevations panel, the comparisons across alternatives and flow categories are the same as in the EOWY elevations panel, but the distributions of elevations shift lower since Lake Powell generally reaches its minimum elevation in March before spring runoff begins, and elevations increase by EOWY.

Figure 3-8
WY Minimum and EOWY Elevations and Storage Volumes of Lake Powell

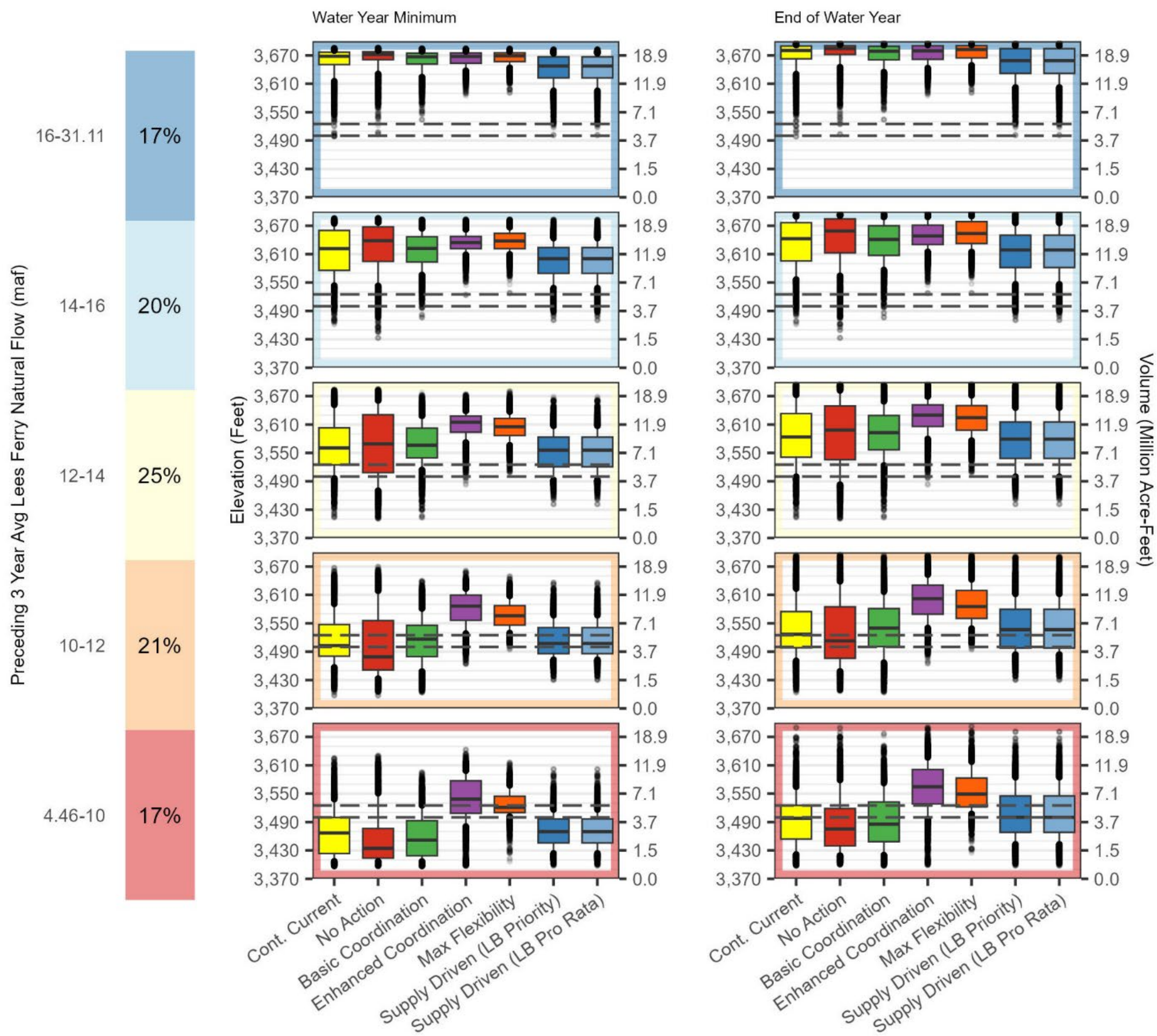
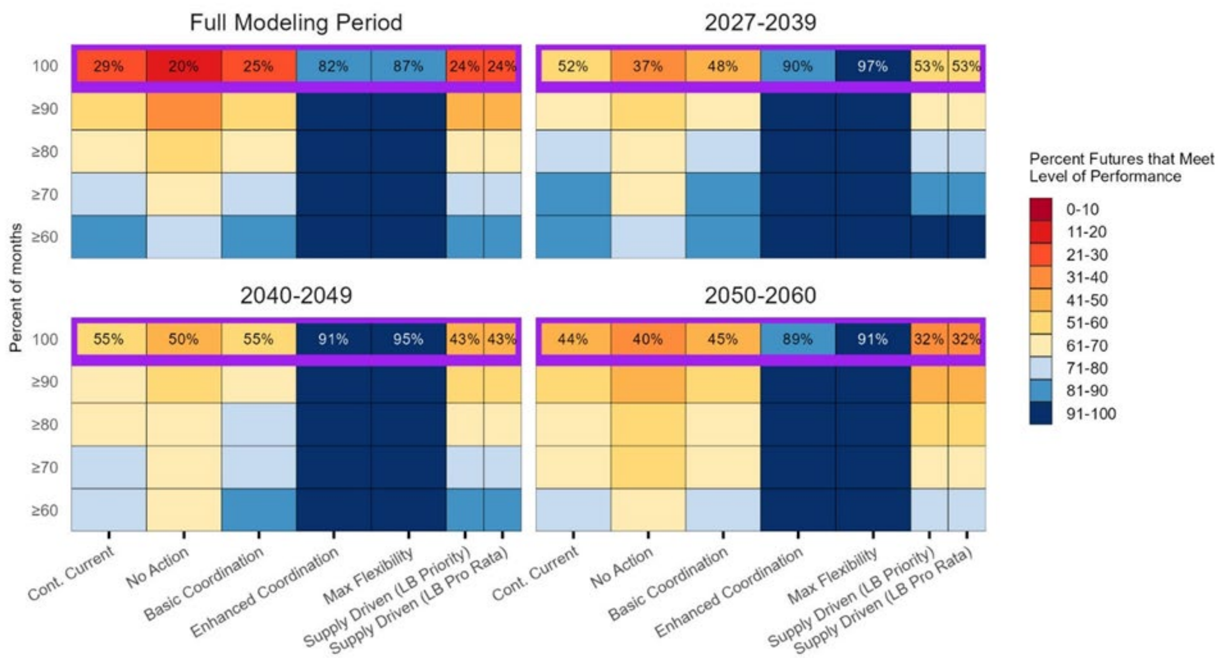


Figure 3-9 below depicts the performance of each alternative with respect to keeping Lake Powell above an elevation of 3,500 feet. Elevation 3,500 feet is important because it provides a 10-foot buffer for water supply and hydropower, which are critically affected at an elevation of 3,490 feet.

Figure 3-9
Lake Powell 3,500 Feet: Robustness.
Percent of futures in which Lake Powell elevation stays above 3,500 feet in the percent of months specified by each row



When looking across the full modeling period (which includes the full range of potential hydrologic futures) the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative are the most robust at staying above the critical threshold of 3,500 feet 100 percent of the months, doing so in 87 percent and 82 percent of the futures, respectively. On the other hand, the Basic Coordination Alternative, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), the No Action Alternative, and the CCS Comparative Baseline are much less robust at staying above 3,500 feet, with the No Action Alternative being the least robust. The robustness scores improve when analyzing shorter modeling periods because it is easier to stay above 3,500 feet for shorter periods than the full 34-year simulation. However, in these shorter periods, robustness trends from the full modeling period still hold.

These trends are supported by a vulnerability analysis, shown in **Figure TA 3-8** in **TA 3**, Hydrologic Resources, which looks at flow conditions that could cause Lake Powell elevations to fall below 3,500 feet for any month (which, for this analysis, is considered an undesirable performance). For the Basic Coordination Alternative, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), the No Action Alternative, and the CCS Comparative Baseline, undesirable performance occurs under similar conditions: when the driest modeled 10-year average Lees Ferry flow is around 11.6 to 11.9 maf. For the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative, which are the most robust alternatives for keeping Lake Powell elevations about 3,500 feet, undesirable performance occurs under much drier conditions, when the modeled 10-year average Lees Ferry flow is closer to 8.0 and 8.9 maf, respectively. As a historical reference, the driest observed 10-year average Lees Ferry flow was 11.8 maf and occurred from 2012 to 2021.

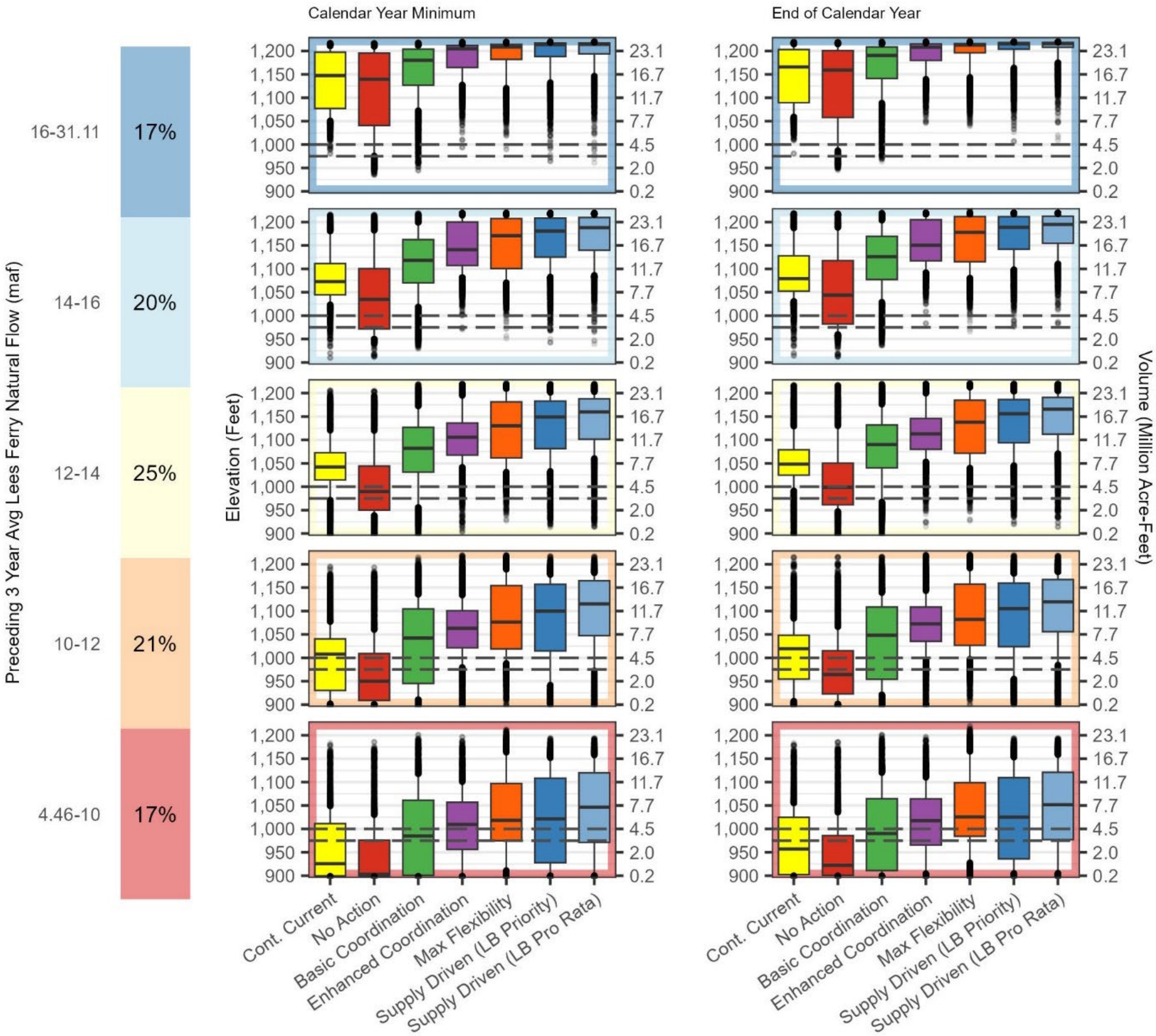
A second robustness and vulnerability analysis was conducted for Lake Powell at a higher elevation of 3,525 feet for a lower frequency of time, 90 percent of months over the full analysis period. This elevation threshold is important because it provides a 35-foot buffer from 3,490 feet, and it is also the elevation at which additional releases from CRSP Upper Initial Units may be triggered. The lower frequency was chosen because it provides a reasonable amount of flexibility to go below 3,525 feet occasionally in very dry hydrology. Similar to the first analysis, the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative are the most robust at staying above the critical threshold of 3,525 feet 90 percent of the months. These two alternatives become vulnerable when the modeled 10-year average Lees Ferry flow is 9.4 and 10.1 maf, respectively. Similarly, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the least robust. Refer to **Figure TA 3-9** and **Figure TA 3-10** in **TA 3**, Hydrologic Resources, for the robustness heatmap and vulnerability plot associated with 3,525 feet.

Lake Mead Reservoir Elevations

Refer to **Table TA 3-5** in **TA 3**, Hydrologic Resources, for a list of critical elevations at Lake Mead. A statistical breakdown of CRSS modeling results for end of calendar year (EOCY) elevations and minimum CY elevations at Lake Mead can be found in **Table TA 3-6** and **Table TA 3-7** in **TA 3**, Hydrologic Resources, respectively.

Figure 3-10 below looks at the response of Lake Mead CY minimum elevations, and EOCY elevations and storage volumes to different hydrologic conditions under different alternatives by looking at the preceding three-year average of Lees Ferry natural flow. The figure visualizes the same data that is included in **Table TA 3-6** and **Table TA 3-7** in two side by side conditional box plot panels. In each flow category shown in the box plots, the key elevations of 1,000 feet and 975 feet are identified with dashed lines. These elevations are important because they provide a 50-foot and a 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. A larger buffer above the hydropower and critical infrastructure elevations is used at Lake Mead than at Lake Powell because Reclamation is required to deliver water orders that have already been approved and therefore does not have as much flexibility to adjust releases from Hoover Dam as from Glen Canyon Dam.

Figure 3-10
CY Minimum and EOCY Elevations and Storage Volumes of Lake Mead



For all alternatives and the CCS Comparative Baseline, median EOCY elevations at Lake Mead decrease as flow categories become drier and generally follow the same trend. This is because Lake Mead operations vary widely across alternatives, and the impacts from policy operations can be seen more markedly in Lake Mead elevations. Across all potential flow conditions, the Supply Driven Alternative (LB Pro Rata approach) consistently has the highest median reservoir elevations, followed by the Supply Driven Alternative (LB Priority approach) which has the second highest. Conversely, the No Action Alternative consistently has the lowest median and interquartile reservoir elevations across all potential flow categories. The 25th percentile for the No Action Alternative approaches 975 feet even within the Moderately Wet Flow Category (14.0-16.0 maf). The CCS Comparative Baseline consistently has the second lowest median and interquartile reservoir elevations.

In the Critically Dry Flow Category (4.46–10.0 maf), the median EOCY elevations for the Supply Driven Alternative (LB Pro Rata approach), the Supply Driven Alternative (LB Priority approach), the Maximum Operational Flexibility Alternative, and the Enhanced Coordination Alternative are 1,050 feet, 1,023 feet, 1,021 feet, and 1,017 feet, respectively. For these alternatives, the EOCY median reservoir elevations that stay notably above both critical buffer threshold elevations of 1,000 feet and 975 feet, for all potential flow conditions. Conversely, for the Basic Coordination Alternative, in the Critically Dry Flow Category (4.46–10.0 maf), the median EOCY elevation drops below the 1,000 feet critical buffer threshold to 989 feet. The CCS Comparative Baseline and the No Action Alternative both have EOCY medians that shift below both thresholds, to 960 feet and 923 feet, respectively.

In the drier flow categories, the variability range of EOCY elevations becomes wider for all of the action alternatives except for the Maximum Operational Flexibility Alternative. The Maximum Operational Flexibility Alternative has a relatively similar range of interquartile values across all flow categories, with 25th percentile values that reliably stay above 975 feet.

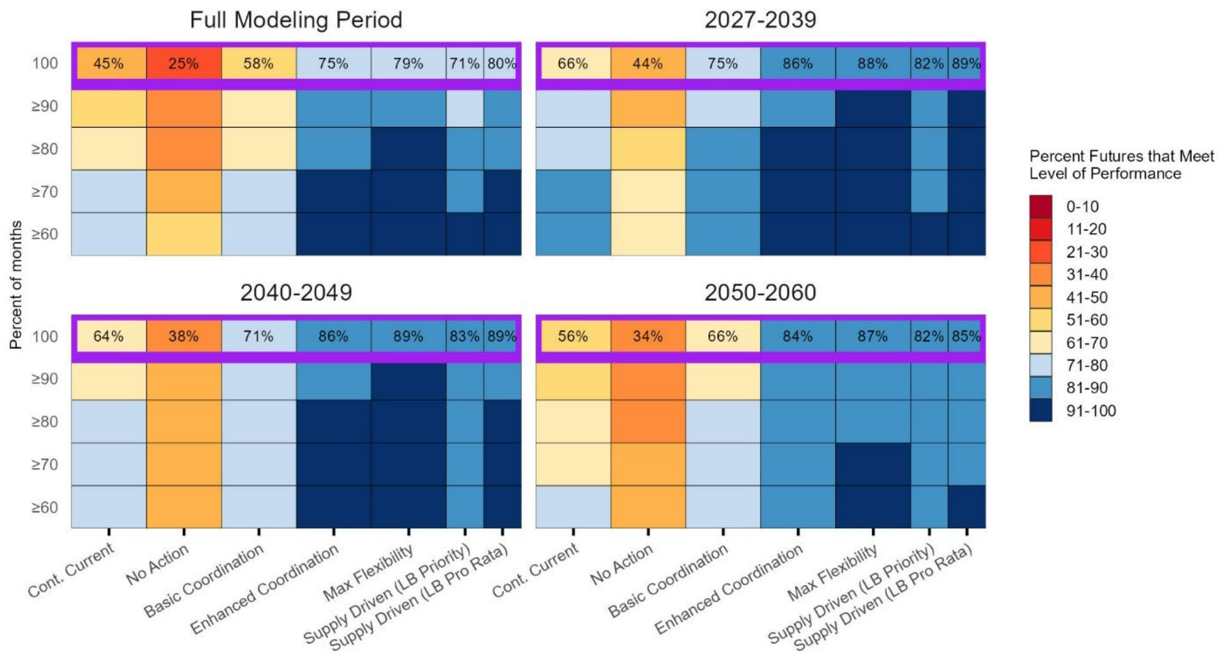
For the CY minimum elevations panel, the comparisons across alternatives and flow categories are the same as in the EOCY elevations panel, and distributions are similar. However, some median elevations are slightly lower than for the EOCY elevations.

Figure 3-11 below shows how each alternative performs with respect to keeping Lake Mead above elevation 975 feet. Elevation 975 feet is important because it provides a 25-foot buffer to protect critical infrastructure and hydropower, which can no longer be produced at elevation 950 feet.

When looking across the full modeling period (which includes the full range of potential hydrologic futures) the Supply Driven Alternative (LB Pro Rata approach), the Maximum Operational Flexibility Alternative, and the Enhanced Coordination Alternative are the most robust at staying above the critical threshold of 975 feet 100 percent of the months, doing so in 80 percent, 79 percent, and 75 percent of the futures, respectively. These trends are supported by a vulnerability analysis shown in **Figure TA 3-13** in **TA 3**, Hydrologic Resources, which looks at flow conditions that could cause Lake Mead elevations to fall below 975 feet for any month. The Supply Driven Alternative (LB Pro Rata approach), the Maximum Operational Flexibility Alternative, and the Enhanced Coordination Alternative become vulnerable under similar conditions: when the modeled 20-year average Lees Ferry flow is around 10.0 to 10.5 maf.

The Supply Driven Alternative (LB Priority approach) and the Basic Coordination Alternative are less robust at staying above 975 feet, becoming vulnerable when the 20-year Lees Ferry flow is 10.9 maf and 11.4 maf, respectively. On the other hand, the CCS Comparative Baseline and the No Action Alternative are much less robust at staying above 975 feet. These two alternatives become vulnerable when the modeled 20-year average Lees Ferry flow is 11.9 and 12.6 maf, respectively. As a historical reference, the driest observed 20-year average Lees Ferry flow was 12.5 maf and occurred from 2002 to 2021. Similar to the robustness heatmap for Lake Powell, the robustness scores improve when analyzing shorter modeling periods because it is easier to stay above 975 feet for shorter periods than for the full 34-year simulation.

Figure 3-11
Lake Mead 975 Feet: Robustness.
Percent of futures in which Lake Mead elevation stays above 975 feet in the percent of months specified by each row



A second robustness and vulnerability analysis was conducted for Lake Mead at a higher elevation of 1,000 feet for a lower frequency of time, 90 percent of months over the full analysis period. Similar to the first analysis, the Supply Driven Alternative (LB Pro Rata approach), the Maximum Operational Flexibility Alternative, and the Enhanced Coordination Alternative are the most robust at staying above the critical threshold of 1,000 feet 90 percent of the months. These alternatives become vulnerable under similar conditions: when the modeled 20-year average Lees Ferry flow is around 9.9 and 10.1 maf. The CCS Comparative Baseline and the No Action Alternative are much less robust at staying above 1,000 feet. Refer to **Figure TA 3-14** and **Figure TA 3-15** in **TA 3**, Hydrologic Resources, for the robustness heatmap and vulnerability plot associated with 1,000 feet.

Lake Mohave and Lake Havasu Elevations

Lake Mohave and Lake Havasu are operated under existing rule curves that determine specific target elevations at the end of each month. The existing rule curves were used in the CRSS model and applied to operations for all alternatives and the CCS Comparative Baseline. As such, water surface elevations at Lake Mohave and Lake Havasu are not affected.

Issue 2: System Storage

System storage is anticipated to be affected by the various alternatives as the result of changes to operational activities. The impacts on various combinations of system storage are summarized below. Refer to **Section TA 3.2.2**, Issue 2: System Storage, in **TA 3**, Hydrologic Resources, for details regarding impacts.

Combined System Storage at Lake Powell and Lake Mead

Analysis of the combined storage across Lake Powell and Lake Mead helps to understand the overall condition of the Colorado River system. Based on this analysis, the primary drivers of Colorado River system conditions are related to assumptions for shortage operations and conservation activities. Refer to **Table TA 3-11** in **TA 3**, Hydrologic Resources, for a statistical breakdown of CRSS modeling results for EOWY combined system storage at Lake Powell and Lake Mead as a percentage of the total storage capacity. Refer to **Figure TA 3-18** in **TA 3** for the box plot representation of the combined system storage of Lake Powell and Lake Mead.

For all alternatives and the CCS Comparative Baseline, EOWY Lake Powell and Lake Mead combined system storage capacities decrease as hydrologic conditions become drier and each alternative generally follows the same trend across all flow categories. For example, the Maximum Operational Flexibility Alternative consistently has the highest combined storage across all flow categories. The alternatives, listed in order from highest Lake Powell and Lake Mead combined system storage to lowest combined storage in all flow categories, are Maximum Operational Flexibility Alternative, Enhanced Coordination Alternative, Supply Driven Alternative (LB Pro Rata approach), Supply Driven Alternative (LB Priority approach), Basic Coordination Alternative, CCS Comparative Baseline, and the No Action Alternative. In the Critically Dry Flow Category (4.46–10.0 maf), the highest median combined storage volume is 27.6 percent, for both the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative. The Supply Driven Alternative (LB Pro Rata approach) has the second highest combined storage volume of 26.1 percent. As a historical reference, the lowest observed EOWY combined storage was 26.55 percent of full and occurred in September 2022.

Combined System Storage at CRSP Reservoirs

Analysis of the combined storage across CRSP reservoirs helps to understand the overall status of Lake Powell and the CRSP Upper Initial Units (Flaming Gorge, Navajo, and Blue Mesa reservoirs). Lake Powell makes up approximately 80 percent of the total CRSP storage capacity, so trends in combined storage capacity are primarily controlled by Lake Powell operations. The CRSP Upper Initial Unit reservoirs can be operated in a way that releases flows to help bolster elevations in Lake Powell and protect Glen Canyon Dam infrastructure. Refer to **Table TA 3-12** in **TA 3** for a statistical breakdown of CRSS modeling results for EOWY combined system storage at CRSP reservoirs as a percentage of the total storage capacity. Refer to **Figure TA 3-19** in **TA 3** for the box plot representation of the combined system storage at CRSP reservoirs.

The alternatives generally perform similarly under the Wet Flow Category (16–31.11 maf), except for the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) which have the lowest median combined CRSP reservoir storage (as a percent of the total capacity). As flow categories become drier, combined CRSP reservoir storage decreases and differences between alternatives becomes more apparent. Similar to trends seen for Lake Powell reservoir elevations, the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintain the highest combined CRSP reservoir storage capacities in drier flow conditions. Trends differ from those seen for Lake Powell elevations for the lower performing alternatives in the Dry Flow Category (10.0–12.0 maf). The No Action Alternative has a higher median combined CRSP reservoir storage capacity than the

CCS Comparative Baseline and the Basic Coordination Alternative (whereas, the No Action Alternative had the lowest median Lake Powell elevations).

Combined System Storage at Seven Reservoirs

Analysis of the seven-reservoir system storage (CRSP Upper Initial Units of Flaming Gorge, Navajo, and Blue Mesa Reservoirs, as well as Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu) volumes over time can be used to better understand overall system conditions. Refer to **Table TA 3-13** in **TA 3** for a statistical breakdown of CRSS modeling results for EOWY combined system storage of the seven reservoirs as a percentage of the total storage capacity. Refer to **Figure TA 3-20** in **TA-3** for the box plot representation of the combined system storage of the seven reservoirs.

Lake Powell and Lake Mead make up approximately 90 percent of the total seven-reservoir system storage capacity, so trends in seven-reservoir storage capacity closely resemble trends for the Lake Powell and Lake Mead combined storage capacity. As such, the alternatives, listed in order from highest combined seven-reservoir storage in all flow categories to lowest combined storage in all flow categories, are the Maximum Operational Flexibility Alternative, Enhanced Coordination Alternative, Supply Driven Alternative (LB Pro Rata approach), Supply Driven Alternative (LB Priority approach), Basic Coordination Alternative, and the No Action Alternative. This performance ranking is the same as the Lake Powell and Lake Mead combined storage ranking.

Issue 3: Reservoir Releases

Releases from reservoirs are anticipated to be affected by the various alternatives as the result of changes to operational activities. The impacts on reservoir releases are summarized below. Refer to **Section TA 3.2.3**, Issue 3: Reservoir Releases, **TA 3**, Hydrologic Resources, for details regarding impacts on reservoir releases.

Glen Canyon Dam (Lake Powell) Releases

Generally, alternatives that prioritize higher elevations in Lake Powell result in lower median annual releases from Glen Canyon Dam. This trend demonstrates the inverse tradeoffs between maintaining reservoir elevations to protect critical infrastructure and annual releases from reservoirs. Refer to **Table TA 3-14** in **TA 3** for a statistical breakdown of CRSS modeling results for EOWY releases from Glen Canyon Dam. Refer to **Figure TA 3-21** in **TA 3** for the box plot representation of the EOWY releases from Glen Canyon Dam. In addition to annual releases, 10-year releases from Glen Canyon Dam are also considered. Refer to **Table TA 3-15** and **Figure TA 3-22** in **TA 3** for modeled results for the 10-year Glen Canyon Dam releases.

Annual releases from Glen Canyon Dam are highest in the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) in the wetter hydrologic conditions; however, as conditions become drier the Basic Coordination Alternative, No Action Alternative, and the CCS Comparative Baseline have higher annual releases, reflecting fewer policy actions to preserve storage. In the Average Flow Category (12.0–14.0 maf), when the variability in releases is the lowest between alternatives, the median EOWY releases from Glen Canyon Dam are 7.87 maf (the Enhanced Coordination Alternative), 8.17 maf (the Maximum Operational Flexibility Alternative), 8.23 maf (the Basic Coordination Alternative, the No Action Alternative, and the CCS Comparative Baseline), and 8.39 maf (the Supply Driven Alternative [both LB Priority and LB Pro Rata approaches]). As flow conditions get drier, the range of variability in each alternative gets larger. In the Critically Dry Flow category (4.46–10.0 maf), the No Action Alternative has the largest variability in releases; meanwhile, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) has the smallest variability in releases.

The 10-year Glen Canyon Dam releases generally follow the trends seen for the annual Glen Canyon Dam releases with some deviations that account for different potential hydrologic conditions. In the Average Flow Category (12.0–14.0 maf), the median 10-year Glen Canyon Dam releases for all alternatives and the CCS Comparative Baseline are situated near 80.0 maf. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) have the highest median 10-year releases of 83.0 maf. The Enhanced Coordination Alternative has the lowest median 10-year release of 79.8 maf.

The Lee Ferry Compact Point is located 17 miles downstream of Glen Canyon Dam and 1 mile downstream from the Paria River. The 10-year flows at the Lee Ferry Compact Point generally follow the trends seen for the 10-year Glen Canyon Dam releases, although the flows are slightly higher to account for incoming flows in the Paria River. The median 10-year flow through the Lee Ferry Compact Point is the highest under the Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) (84.6 maf each). The No Action Alternative (83.6 maf) has the second highest median flow, followed by the CCS Comparative Baseline (83.3 maf), the Basic Coordination Alternatives (83.0 maf), the Maximum Operational Flexibility Alternative (82.3 maf), and finally the Enhanced Coordination Alternative (81.3 maf), which has the lowest median flow.

Hoover Dam (Lake Mead) Releases

Generally, alternatives with higher Lake Mead elevations correspond to lower releases from Hoover Dam, especially in the Average Flow Category (12.0–14.0 maf). However, the range of interquartile variability for releases from Hoover Dam is wide, especially in the Wet Flow Category (16–31.11 maf) and the Critically Dry Flow Category (4.46–10.0 maf), indicating more variability in releases as flow conditions get more extreme (in both directions). Refer to **Table TA 3-17** in **TA 3** for a statistical breakdown of CRSS modeling results for EOCY releases from Hoover Dam. Refer to **Figure TA 3-24** in **TA 3** for the box plot representation of the EOCY releases from Hoover Dam.

For the No Action Alternative, the Basic Coordination Alternative, the Maximum Operational Flexibility Alternative, and the CCS Comparative Baseline the interquartile range of releases from Hoover Dam is smallest in the Average Flow Category (12.0–14.0 maf) and becomes wider in the Wet Flow Category (16.0-31.11 maf) and the Critically Dry Flow Category (4.46–10.0 maf). For the Enhanced Coordination and Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) the interquartile ranges are fairly consistent between the Average Flow Category (12.0–14.0 maf) and the Critically Dry Flow Category (4.46–10.0 maf).

In the Average Flow Category (12.0–14.0 maf), the lowest median EOCY releases from the Hoover Dam are 7.7 maf (the Supply Driven (LB Pro Rata approach) and the Enhanced Coordination Alternative). The median Hoover Dam releases increase to 7.8 maf (the Supply Driven (LB Priority approach) and the Maximum Operational Flexibility Alternative), 8.1 maf (the Basic Coordination

Alternative), 8.5 maf (CCS Comparative Baseline), and 8.7 maf (the No Action Alternative). As flow conditions get drier, the annual releases from Hoover Dam begin to differ for alternatives. The No Action Alternative is no longer the highest annual release, instead dropping down to the third lowest annual release, after the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative (which are tied for the lowest annual releases of 6.57 maf). Meanwhile, the Basic Coordination Alternative has the highest annual release of 7.7 maf.

Davis Dam (Lake Mohave), Parker Dam (Lake Havasu) Releases, and Morelos Diversion Dam

Releases from Davis Dam, at Lake Mohave, are based on target elevations defined by the existing rule curve. Inflows into Lake Mohave vary across alternatives, and because elevations are kept to the range determined by the rule curve, releases from Davis Dam subsequently vary across alternatives. Releases from Davis Dam follow similar trends to Hoover Dam releases. Similarly, releases from Parker Dam, at Lake Havasu, vary by alternative because they are based on target elevations defined by the existing rule. Releases from Parker Dam follow similar trends as Hoover Dam and Davis Dam releases.

Issue 4: River Flows

River flows in the downstream reaches of the Colorado River are anticipated to be affected by the various alternatives as the result of changes to operational activities. Effects on river flows in specific reaches mirror trends seen for reservoir releases in Issue 3. For example, as flow conditions get drier river flows decrease, driven by the decrease of reservoir releases under drier flow conditions. Alternatives that result in higher reservoir releases also result in higher flows through the reaches downstream of the corresponding dams. The impacts on each river reach are summarized below. Refer to **Section TA 3.2.4**, Issue 4: River Flows, in **TA 3**, Hydrologic Resources, for details regarding impacts on river flows within specific reaches of the Colorado River.

Downstream of Glen Canyon Dam

Reach 1 of the river extends 292 miles from Glen Canyon Dam, through GCNP, to the reservoir pool for Lake Mead. River flows in this reach primarily consist of controlled releases from Glen Canyon Dam at Lake Powell and mirror trends seen for reservoir releases in Issue 3. Inflows to this reach from the perennial Paria River and Little Colorado River make up approximately 3 percent of the total flows in this reach and were modeled in CRSS as the same across alternatives.

As shown in the analysis for releases for Glen Canyon Dam under Issue 3, in the Average Flow Category (12.0–14.0 maf), the median WY flow downstream from Glen Canyon Dam are 8.39 maf under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), 8.23 maf under the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives, 8.17 maf under the Maximum Operational Flexibility Alternative, and 7.87 maf under the Enhanced Coordination Alternative. The CCS Comparative Baseline typically has median annual flows between the Basic Coordination Alternative and the No Action Alternative.

During drier flow conditions, the Basic Coordination Alternative has the highest median annual flows in Reach 1, followed by the No Action Alternative and then the CCS Comparative Baseline. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) has the next highest river flows, followed by the Maximum Operational Flexibility Alternative. The Enhanced Coordination Alternative has the lowest median annual flows in Reach 1 under the driest flow conditions.

Downstream of Hoover Dam to Imperial Dam (Reaches 2–6)

River flows downstream of Hoover Dam typically follow similar trends and patterns across the same flow categories for the different alternatives. For example, under the Average Flow Category (12.0–14.0 maf), the No Action Alternative has the highest median annual flow in the reaches from Hoover Dam to Imperial Dam, followed by the CCS Comparative Baseline and then the Basic Coordination Alternative. The Enhanced Coordination Alternative consistently has the lowest median annual flow in the Average Flow Category (12.0–14.0 maf).

Trends deviate somewhat as flow conditions get drier. For example, in the Critically Dry Flow Category (4.46–10.0 maf) the Basic Coordination Alternative has the highest median annual flow in the reaches from Hoover Dam to Imperial Dam. The Supply Driven Alternative (LB Priority approach) has the second highest median annual flow. The Supply Driven Alternative (LB Pro Rata approach) has the third highest flows, and the No Action Alternative has the fourth highest flows for the reach between Hoover Dam and Lake Havasu. However, downstream of Lake Havasu, the No Action Alternative and Supply Driven Alternative (LB Pro Rata approach) switch rankings. The Enhanced Coordination Alternative has the lowest median annual flow from Hoover Dam to Imperial Dam. So, while the No Action Alternative has higher river flows in the Wet and Average Flow Category conditions, as conditions get drier, the No Action Alternative results in some of the lower river flows and the largest range in variability. The Enhanced Coordination Alternative consistently has the lowest median annual flow compared to the other alternatives but a smaller range in variability of flows.

Downstream of Imperial Dam (Reaches 6–7)

River flows in Reach 6 and an upper portion of Reach 7 primarily comprise releases from Imperial Dam which are dictated by delivery requirements. The alternatives analyzed do not affect these deliveries; therefore, the required flows in these reaches are similar across most hydrologic traces. While these alternatives have similar values, the Supply Driven Alternative (LB Priority approach) consistently has the highest median river flows across all flow categories. The lowest median river flows in this reach occur under either the Enhanced Coordination Alternative (during wetter flow conditions) or the Maximum Operational Flexibility Alternative (during drier flow conditions).

River flows in the lower portion of Reach 7 through the limitrophe are infrequent and only occur when Morelos Diversion Dam releases water in excess of Mexico's scheduled delivery. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) are the most likely to see flows occur in the limitrophe in this reach, doing so in less than 50 percent of the hydrologic futures in the Wet Flow Category (16–31.11 maf). The No Action Alternative and the CCS Comparative Baseline are the least likely to see flows occur in this reach, doing so in less than 10 percent of hydrologic futures in the Wet Flow Category (16–31.11 maf).

Issue 5: Groundwater

Groundwater elevations adjacent to reservoirs and within specific reaches along the Colorado River may be affected by the various alternatives, depending on the hydraulic connectivity and geotechnical characteristics of the area. In reaches of the Colorado River that have a direct connection to groundwater, changes in river flows and changes in reservoir elevations are anticipated to affect groundwater elevations. The reaches that are anticipated to have impacts on groundwater as the result of changes to operational activities are summarized below. Refer to **Section TA 3.2.5**, Issue 5: Groundwater, in **TA 3**, Hydrologic Resources, for details regarding impacts on groundwater within specific reaches of the Colorado River.

Reaches Anticipated to Have Impacts

Changes in water surface elevations at Lake Powell may be reflected as fluctuations in groundwater elevations adjacent to the reservoir. The Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative are the most robust at maintaining elevations at Lake Powell and are therefore anticipated to have the highest associated groundwater levels. The No Action Alternative is the least robust and is therefore anticipated to have the lowest associated groundwater levels.

Reaches 3 through 5 of the Colorado River are made up of alluvial fill groundwater basins and are anticipated to have impacts on groundwater associated with changes in river flows due to operational activities. Impacts on groundwater elevations mirror trends seen for river flows in Issue 4, where alternatives that result in higher flows in the reach can likewise be expected to result in higher groundwater elevations. For Reaches 3, 4, and 5 during dry flow conditions, the Basic Coordination Alternative (which distributes shortages using the Priority system) is anticipated to result in higher groundwater elevations compared to the CCS Comparative Baseline and all other action alternatives. For these same reaches and flow conditions, the Enhanced Coordination Alternative (which distributes shortages using the Pro Rata approach) is anticipated to result in lower groundwater elevations compared to the CCS Comparative Baseline and all other action alternatives. All other action alternatives perform similarly, with some action alternatives performing better in one reach over another, with the differences corresponding to the upstream reservoir releases. Releases are mainly driven by the method of shortage distribution in the Lower Division States. Flows in Reach 7 through the limitrophe are infrequent and therefore have limited effect on groundwater elevations; however, the Supply Driven Alternative (LB Pro Rata approach) is the most likely to result in infrequent flows in this reach.

Reaches Not Anticipated to Have Impacts

Reaches of the Colorado River that contain bedrock, that consist of lined canals, or which otherwise have limited hydraulic connectivity to groundwater are not anticipated to have impacts on groundwater associated with changes to operational activities. These portions of the analysis area include the Grand Canyon, Lake Mead, Reach 2 within the Black Canyon, and Reach 6 which diverts Colorado River water into lined canals. Likewise, reservoirs that maintain the same water surface elevation regardless of alternative are not anticipated to affect groundwater levels. These reservoirs include Lake Mohave and Lake Havasu, which will continue to be operated under their existing release rule curves, which keeps reservoir elevations within a tight range.

Summary Comparison of Alternatives

Beginning with water surface elevations at Lake Powell, generally, all alternatives perform similarly under wet potential hydrologic futures. As potential modeled hydrologic futures shift into drier flow categories, water surface elevations decrease, under all alternatives, and differences between alternatives become more apparent. This is because decreasing Lake Powell elevations trigger different operations that vary widely across alternatives. The Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative have the highest and second highest ranges of EOWY Lake Powell elevations under dry conditions. These alternatives are the most robust at staying above the critical buffer threshold elevation of 3,500 feet across the full modeling period. In contrast, the Basic Coordination Alternative, the No Action Alternative, and the CCS Comparative Baseline have the lowest ranges of EOWY reservoir elevations under dry conditions, with the No Action Alternative resulting in the lowest minimum elevations during the entire WY.

Generally, alternatives that prioritize higher elevations in Lake Powell result in lower annual releases from Glen Canyon Dam with a larger range in variability of releases. Therefore, as potential modeled futures become drier, the median annual releases from Glen Canyon Dam at Lake Powell are the lowest in the Enhanced Coordination Alternative and second lowest in the Maximum Operational Flexibility Alternative. The Basic Coordination Alternative, No Action Alternative, and the CCS Comparative Baseline have the higher annual releases. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) have median reservoir elevations that are generally between these. This inverse trend demonstrates the tradeoffs between maintaining reservoir elevations to protect critical infrastructure and annual releases from reservoirs.

The general trend where alternatives with higher reservoir elevations correspond to lower reservoir releases and vice versa continues downstream to Lake Mead, with the caveat that results at Lake Mead are more variable than at Lake Powell. This is because operations vary widely across alternatives and the impacts from policy operations can be seen more markedly in Lake Mead elevations. As potential modeled hydrologic conditions shift into drier flow categories, water surface elevations at Lake Mead decrease and variability increases. However, each alternative generally follows the same trend across all flow categories. For example, the Supply Driven Alternative (LB Pro Rata approach), consistently has the highest EOCY median reservoir elevations across all potential flow conditions. The alternatives, listed in order from highest median EOCY elevations to lowest elevations across all flow categories, are the Supply Driven Alternative (LB Pro Rata approach), Supply Driven Alternative (LB Priority approach), Maximum Operational Flexibility Alternative, Enhanced Coordination Alternative, Basic Coordination Alternative, CCS Comparative Baseline, and No Action Alternative. The Supply Driven Alternative (LB Pro Rata approach), the Maximum Operational Flexibility Alternative, the Enhanced Coordination Alternative, and the Supply Driven Alternative (LB Priority approach) are the most robust at staying above the critical threshold of 975 feet 100 percent of the months.

The combined system storage of Lake Powell and Lake Mead, which can be used to assess the overall condition of the Colorado River system, follows general trends similar to the ones observed in the analysis of reservoir elevations. For example, combined storage (as a percentage of the total storage capacity) decreases as flow conditions get drier and each alternative generally follows the same trend across all flow categories. The general trends that are observed for the combined system storage capacity of Lake Powell and Lake Mead are a combination of trends seen for each reservoir elevation, individually. For example, for both reservoirs, the No Action Alternative consistently had the lowest median reservoir elevations, so it follows that the No Action Alternative results in the lowest combined storage capacity. This trend is also true for the CCS Comparative Baseline and the Basic Coordination Alternative, which are both among the bottom performers for reservoir elevations and subsequently also for combined storage. However, the top performing alternatives related to reservoir elevation differ for Lake Powell and Lake Mead, resulting in combined storage capacity trends that are a blend of reservoir elevation trends. For example, the Enhanced Coordination Alternative had the highest median elevations at Lake Powell but had the fourth highest median elevations at Lake Mead. This resulted in the Enhanced Coordination Alternative having the second highest combined storage capacity of Lake Powell and Lake Mead.

The alternatives, listed in order from highest Lake Powell and Lake Mead combined system storage to lowest combined storage in all flow categories, are the Maximum Operational Flexibility Alternative, Enhanced Coordination Alternative, Supply Driven Alternative (LB Pro Rata approach), Supply Driven Alternative (LB Priority approach), Basic Coordination Alternative, CCS Comparative Baseline, and the No Action Alternative.

For most reaches of the Colorado River, flows mostly comprise releases from upstream reservoirs discussed in Issue 3, and overall trends for river flows mirror those seen for reservoir releases. Inflows from perennial tributaries are minor and do not change between alternatives. For example, alternatives that prioritize higher reservoir elevations (the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative) generally correspond to lower annual releases and subsequently result in lower Colorado River flows in the reaches between reservoirs. Conversely, alternatives that are not as robust at maintaining reservoir elevations (the Basic Coordination Alternative, No Action Alternative, and the CCS Comparative Baseline) generally correspond to higher reservoir releases and subsequently result in higher Colorado River flows.

In reaches of the Colorado River that have a direct connection to groundwater, changes in river flows and changes in reservoir elevations are anticipated to affect groundwater elevations. Higher reservoir elevations are expected to increase localized groundwater adjacent to reservoirs. Based on this correlation, the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative are expected to result in the highest groundwater elevations adjacent to Lake Powell. The Basic Coordination Alternative, No Action Alternative, and the CCS Comparative Baseline are expected to result in the lowest groundwater elevations. Similarly, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), closely followed by the Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative, are expected to result in the highest groundwater elevations adjacent to Lake Mead. The No Action Alternative and the CCS Comparative Baseline are expected to result in the lowest groundwater elevations. However, since river flow trends are typically inversely correlated with reservoir elevations, the Basic Coordination Alternative is anticipated to have the highest flows in the Colorado River and is therefore assumed to result in the highest groundwater elevations adjacent to the river. The Enhanced Coordination Alternative is anticipated to have the lowest flows in the Colorado River and is therefore assumed to result in the lowest groundwater elevations adjacent to the river.

3.4 Water Deliveries

3.4.1 Affected Environment

Water from the Colorado River is delivered to entities in the Lower Division states and Mexico for domestic and agricultural use, in accordance with the Law of the River. Colorado River water is also used to serve many purposes in the Upper Basin. The geographic scope of this EIS does not extend above Lake Powell and accordingly does not include an analysis of the impact on Upper Basin water users. With respect to Upper Basin conservation, the nexus to the proposed federal action is the storage and delivery of that conserved water in Lake Powell. The effects of this storage in and delivery from Lake Powell are within the scope of the EIS (see **Section 3.3**, Hydrologic Resources, and **TA 3**, Hydrologic Resources), while specific activities that may be undertaken in the Upper Basin to generate the conserved water are not within the scope of this EIS. Any such activities are unknown at this time and will not necessarily require federal decision making. Any federal decisions associated with these conservation activities will be assessed outside of this EIS.

Legal and Policy Framework

The Law of the River is an umbrella term for the collection of laws, compacts, decrees, court decisions, contracts, and regulatory guidelines that govern management and operation of the Colorado River. Most notable among these documents are the Compact, the BCPA, the 1944 Water Treaty, the 1968 Colorado River Basin Project Act, and the 2006 Consolidated Decree (Reclamation 2016). Additional documents defining the Law of the River are further explained in **TA-4**, Water Deliveries.

Apportionments

The Compact apportions 7.5 maf of water per year to the Upper Basin and 7.5 maf of water per year to the Lower Basin, divided at Lee Ferry, Arizona. Water apportionments to the Upper Division States total 7.5 maf and are distributed by the 1948 Upper Colorado River Basin Compact as a percentage of the total amount available for consumptive use each year after the deduction of Arizona's 50 kaf apportionment of Upper Basin water. The water is distributed among Colorado (51.75 percent), Utah (23 percent), Wyoming (14 percent), and New Mexico (11.25 percent). The Upper Division State apportionments have not yet been fully developed. Water apportionments to the Lower Division States total 7.5 maf for consumptive use, subject to annual increases or reductions pursuant to Secretarial determinations of a Surplus or a Shortage condition. Lower Division State apportionments are set by the BCPA as follows: California (4.4 maf), Arizona (2.8 maf), and Nevada (0.3 maf). See **Section 1.8** for a description of historical water use across the Upper and Lower Basins.

Rights to use Colorado River water within the Lower Division States, known as entitlements, are established in accordance with the BCPA and the Consolidated Decree. All of the water apportioned to the Lower Division States is allocated in accordance with these documents. For users in the Lower Division States, entitlements arise through (i) a decreed right, (ii) a Section 5 water delivery contract, or (iii) a Secretarial reservation. The Consolidated Decree lists and quantifies all PPRs in the Lower Division States. PPRs are the highest priority Lower Basin mainstream Colorado River water entitlements that were perfected before June 25, 1929. The Consolidated Decree also lists federal reserved water rights for five Indian reservations. PPRs are satisfied first in order of priority in years when less than 7.5 maf of water is available from the Colorado River for consumptive use in the Lower Division States, before other entitlements are fulfilled.

Storage & Delivery of Conserved and Non-System Water and Treatment of Pre-2027 Intentionally Created Surplus

As outlined in the 2007 Interim Guidelines, Lower Basin entitlement holders can store conserved water in Lake Mead, provided they have an ICS exhibit and an approved ICS contribution plan. ICS can be delivered to the Lower Division States when an "ICS Surplus" condition is determined. Beginning in 2027, guidelines regarding the delivery and creation of ICS will change in accordance with the Lower Basin DCP to incorporate additional thresholds and repayment timelines.

Lower Basin Water Supply Determination

Annually, the Secretary determines the water supply condition for the lower Colorado River mainstream as either Normal, Surplus, or Shortage Conditions based on Lake Mead's projected elevation on January 1. The guidance provides supply thresholds under which the consumptive use from Lake Mead would be lowered below 7.5 maf, as well as outlining coordinated management strategies between Lake Powell and Lake Mead. In 2008–2021, Lake Mead operated under Normal/ICS Surplus Conditions, shifting to Shortage Conditions in 2022–2024 as drought and declining reservoir levels triggered conservation measures. Further historical information is available in **TA-4**, Water Deliveries.

Mexico's Allotment

Mexico's allotment of Colorado River water is described under Article 10 of the 1944 Water Treaty. The 1944 Water Treaty guarantees that 1.5 maf will be delivered to Mexico annually. Additionally, it outlines Surplus Conditions such that no greater than 1.7 maf shall be delivered to Mexico in a given year, and Extraordinary Drought such that deliveries are reduced in proportion to reductions of U.S. consumptive uses. Additional Minute 242 documentation provides guidance for the geographic locations where deliveries from the U.S. will be made. Minute 323 does not change Mexico's allotment, but it does adjust how and under what conditions deliveries occur. For further information regarding Mexico's allotment and pertinent policy, refer to **Appendix M**, International Border Region of the Colorado River.

Distribution of Shortages and Reductions to and within the Lower Division States

The 2007 Interim Guidelines, the 2019 DCP and Minute 323 to the 1944 Water Treaty provide for a maximum of 1.375 maf of shortages and reductions (including DCP Contributions and BWSCP savings). In addition to these required activities, in 2024, SEIS conservation implemented through the 2024 ROD resulted in additional Lower Basin conservation. A summary of the 2007 Interim Guidelines Shortages, 2019 DCP contributions, and SEIS conservation is shown in **Table TA-4-6** in **TA-4**, Water Deliveries.

Shortages are distributed following the priority system for Arizona, California, and Nevada. The state-specific priority systems are outlined in **Tables TA-4-7** through **TA-4-9** in **TA-4**, Water Deliveries. The approximate combined shortage and DCP contributions volumes for Arizona range from 472 kaf to 1 maf. The approximate combined shortage and DCP contribution volumes for

California range from 400 kaf to 750 kaf. The approximate combined volume of Nevada's shortages and DCP contributions ranges from 78 kaf to 100 kaf.

3.4.2 Environmental Consequences

This section compares water deliveries from the Lower Colorado River mainstream under the No Action Alternative, four action alternatives, (as described in **Chapter 2**) and the CCS Comparative Baseline (as described in **Chapter 3, Section 3.2.3**). Also provided is a comparison of Upper Basin conservation across the alternatives. Refer to **TA-4**, Water Deliveries for greater details regarding the analysis of impacts.

Methodology

Reclamation uses the CRSS model for long-term planning studies. The CRSS model simulates Basin conditions decades into the future (the full analysis period is through 2060) and can be used to account for hydrologic uncertainty. Refer to **Appendix A**, CRSS Model Documentation for more details related to model documentation. For background and guidance related to figures used in the full analysis, see **Section 3.2**, Analysis Methods. Additionally, the SAM and ADM were used to analyze potential impacts of the alternatives on individual water users within each Lower Division State under varying levels of shortage. Modeling assumptions for the SAMs and ADMs are summarized in **Appendix E,** DMDU Overview and Approach.

Impact Analysis Area

The geographic scope of the water deliveries analysis is the Colorado River corridor from the upstream limit of full pool elevation of Lake Powell to the downstream limit of the SIB. The geographic scope of this EIS does not extend above Lake Powell and accordingly does not include an analysis of the impact to Upper Basin water users. Although assumptions about Upper Basin conservation are included in various alternatives, no assumptions are made with respect to where conserved water is generated or what specific activities generated the water (see **Appendix B** for more information).

Assumptions

The CRSS model was used to analyze shortage volumes and Lower Basin water deliveries, and the SAMs and ADMs were used to analyze shortage impacts on specific groups of water users. The model also includes assumptions regarding Upper Basin conservation activities but does not make assumptions with respect to conservation by different entities or via specific activities. Refer to their respective appendices for more details related to model assumptions and documentation. All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell and/or Lake Mead (refer to **Chapter 2, Sections 2.6–2.8** for a description of alternatives). Unless otherwise specified, impacts reflect modeling assumptions about voluntary conservation behavior.

Impact Indicators

The following indicators were used to assess impacts on water deliveries due to operational activities: magnitude of shortage volumes, distribution of shortages, and depletions among and within the Lower Division States.

Issue 1: Apportionments to the Upper Division States

The alternatives would not affect apportionments to the Upper Division States. Therefore, no impact analysis is warranted.

Issue 2: Lower Division States Apportionments and Water Entitlements

The approaches to distributing shortages incorporated in all alternatives are designed to explore a wide range of potential concepts and impacts; they do not reflect an intention by Reclamation to alter apportionments or water entitlements. However, because the concepts would affect a range of users, impacts on deliveries to different entities are analyzed in Issues 3 and 5 and addressed in **Appendix C,** Shortage Allocation Model and Alternative Distribution Model Documentation. Once an alternative is selected, the Department will supplement the analysis if necessary.

Issue 3: Lower Division States Water Supply Determinations and Total Water Deliveries

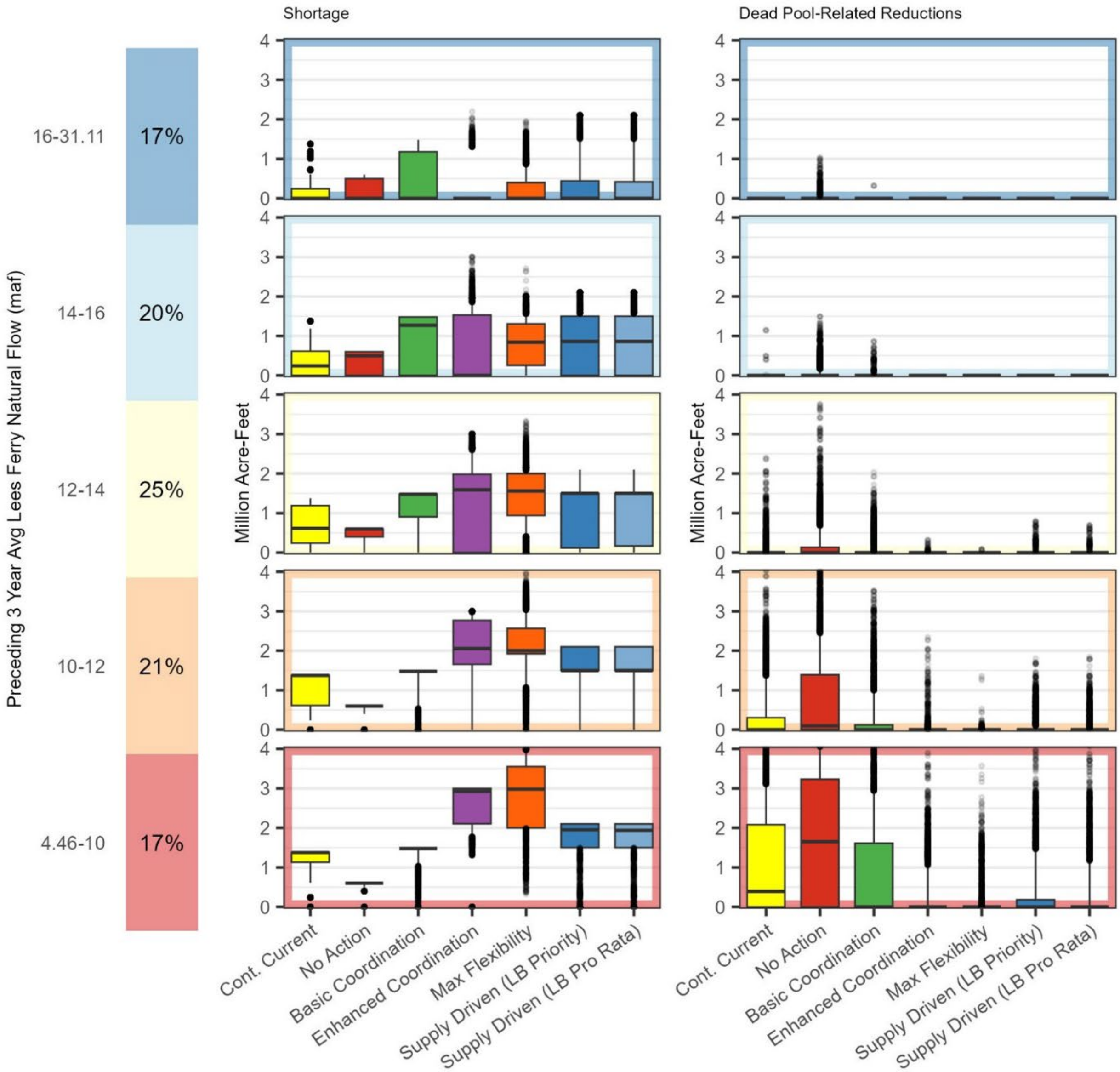
Issue 3 addresses how operational activities affect water deliveries for the Lower Division States and Mexico. This is analyzed through the following key metrics: shortage versus dead pool–related reductions, conservation modeling assumption effects, shortage, annual depletions, and surplus.

Shortage versus Dead Pool–Related Reductions: Comparison for Full Lower Basin

Shortage refers to delivery reductions that are defined as part of an alternative's operations, including reductions to the Basin, state apportionment, or individual entitlement. Volumes and distributions of shortage are described in **Chapter 2**. Dead pool–related reductions occur when there is not enough water in Lake Mead to fully meet downstream demands or when Hoover Dam infrastructure constraints result in releases below the demand volume.

The two columns of boxplots in **Figure 3-12** look at how different alternatives perform in terms of Annual Lower Basin Reductions, reflected as shortage and dead pool–related reductions, over a range of hydrological conditions based on the preceding 3-year average of Lees Ferry natural flow. Reductions are expressed as a total volume of reductions to the Lower Basin, including Mexico. Generally, lower shortage volumes correspond to higher frequency and larger volumes of dead pool–related reductions, seen most prominently in the No Action and Basic Coordination Alternatives. The greatest contrast between alternatives occurs in the Critically Dry Flow Category (4.46–10.0 maf). The No Action Alternative has the lowest median shortage among all alternatives and shares the smallest interquartile range of zero with the Basic Coordination Alternative. In the No Action Alternative and Basic Coordination Alternative, at least 75 percent of the traces reach the maximum shortage level. All action alternatives except for the Basic Coordination Alternative show increases in median shortage compared to the No Action Alternative, with the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative median shortage reaching as high as 2.9 maf and 3.0 maf, respectively. In the Critically Dry Flow Category (4.46–10.0 maf), all action alternatives perform better for dead pool–related reductions than for the CCS Comparative Baseline and the No Action Alternative.

Figure 3-12
Annual Lower Basin Reductions

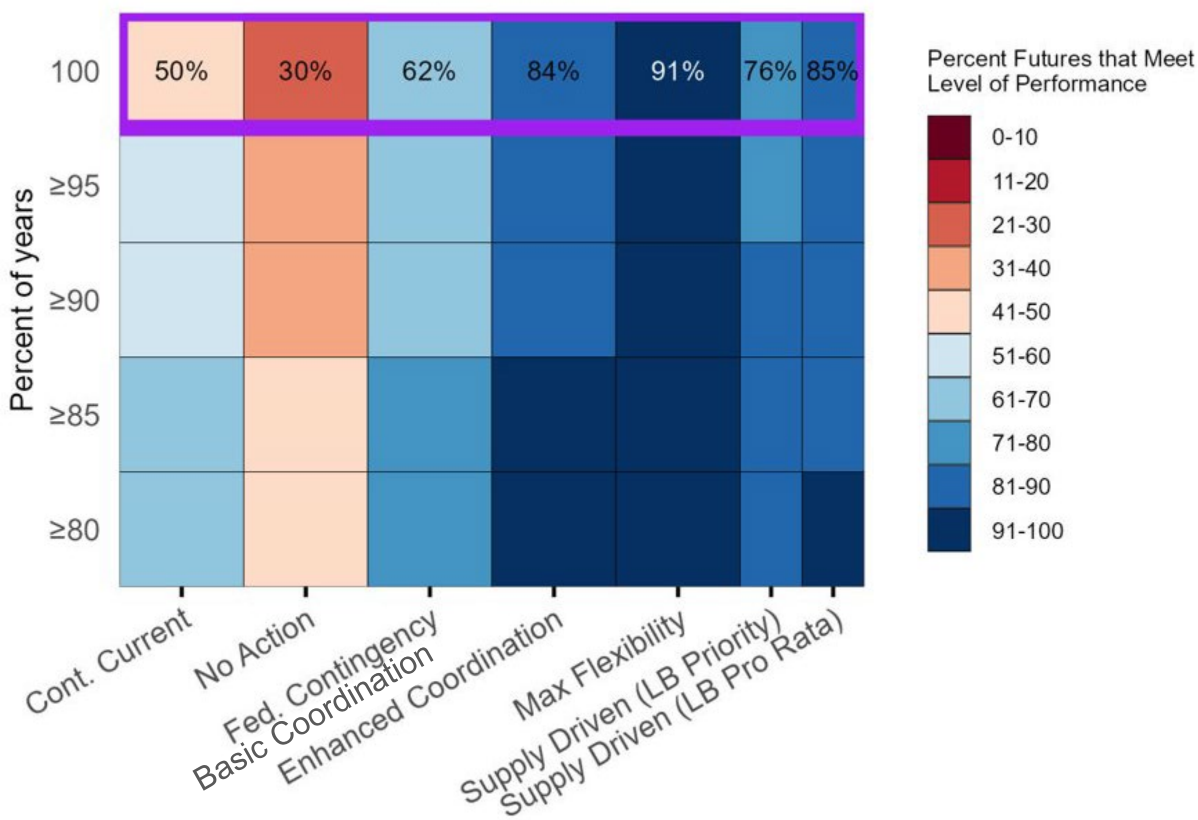


Note: Shortage and dead pool-related delivery reduction volumes include modeling assumptions for reductions in water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current United States policy or a determination of future United States policy regarding deliveries to Mexico. The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

Lake Mead Dead Pool Robustness

Figure 3-13 below depicts the ability of each alternative (columns) to avoid dead pool–related reductions at Lake Mead in the specified percent of years (rows). The highlighted row represents the percentage of futures that an alternative successfully avoids dead pool–related reductions in 100 percent of the years. Keeping Lake Mead above dead pool ensures that water releases can still be made to users, although it does not guarantee the ability to generate power. The Maximum Operational Flexibility Alternative is most robust, avoiding dead pool–related reductions in 91 percent of futures, followed by the Supply Driven Alternative (LB Pro Rata approach) at 85 percent and Enhanced Coordination Alternative at 84 percent, while the No Action Alternative is least robust at only 30 percent.

Figure 3-13
Lake Mead Dead Pool–Related Reductions: Robustness.
Percent of futures in which dead pool-related reductions are avoided in the percent of years specified by each row



Note: Dead pool-related reduction volumes include modeling assumptions for reductions in water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current United States policy or a determination of future United States policy regarding deliveries to Mexico. The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

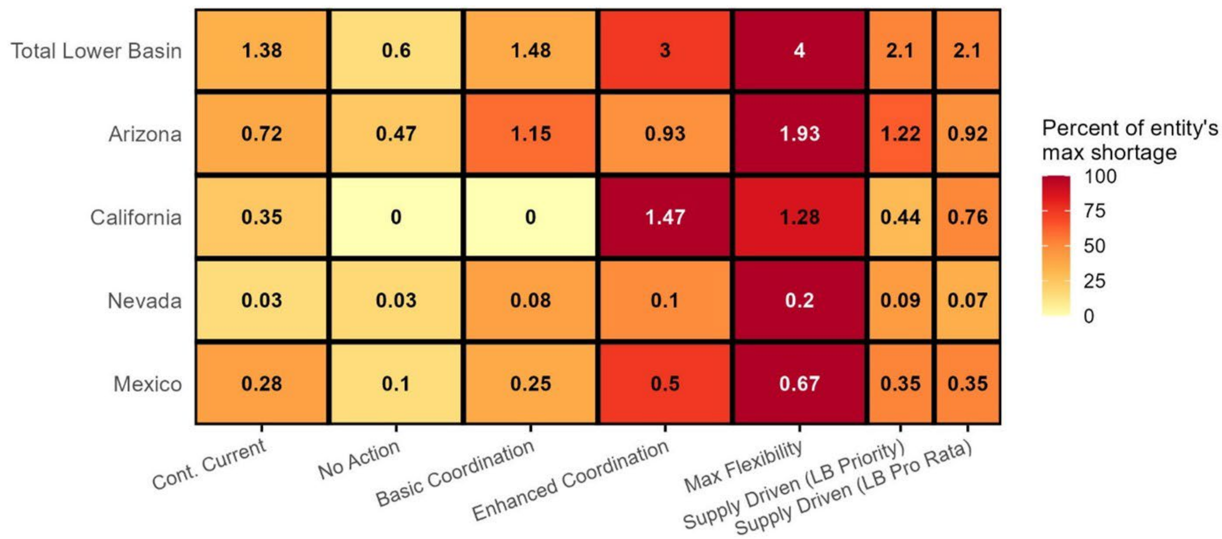
Lake Mead Dead Pool Vulnerability
For this vulnerability analysis, the driest 20-year average Lees Ferry annual flow was determined to be a good predictor of undesirable performance. This definition of undesirable performance is based on the highlighted row in **Figure 3-13**, which determined a future as successful when an alternative avoided dead pool–related reductions 100 percent of the time. The least robust alternative, the No Action Alternative, is vulnerable when flows are below 12.5 maf. The most robust alternative, Maximum Operational Flexibility Alternative, is vulnerable when flows are below 8.0 maf. Further information and detailed figures can be found in **TA-4**, Water Deliveries.

Effects of Modeling Assumptions for Upper Basin and Lower Basin Conservation Activity
Modeling assumptions for conservation activity have minimal effect on median shortages or dead pool–related reductions but influence variability across alternatives and flow categories. Further information and detailed figures can be found in **TA-4**, Water Deliveries.

Shortage
Shortages increase as flow categories become drier. The action alternatives generally have larger shortages compared to the CCS Comparative Baseline and No Action Alternative.

Maximum Shortage
The maximum shortages can be viewed below in **Figure 3-14**, which compares alternatives based on the maximum volume of shortage they apply to the entire Lower Basin and to each state and Mexico. The rows correspond to the entire Lower Basin (top row) and to different states or Mexico, and the columns correspond to different alternatives. Each row has an independent color scale, so the darkest color in each row corresponds to the highest shortage for that entity. California does not have shortages under the No Action Alternative or the Basic Coordination Alternative (both priority-based alternatives). For all other Lower Basin entities, the Maximum Operational Flexibility Alternative imposes the largest maximum shortages, and the No Action Alternative imposes the lowest maximum shortages except for Nevada, where the CCS Comparative Baseline imposes the lowest maximum, closely followed by the No Action Alternative. California takes its largest shortage under the Enhanced Coordination Alternative, due to its pro rata approach to shortage distribution.

Figure 3-14
Maximum Shortage (maf)



Note: The total Lower Basin shortage volume and delivery reduction volume to Mexico include modeling assumptions for reductions in water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current United States policy or a determination of future United States policy regarding deliveries to Mexico. The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

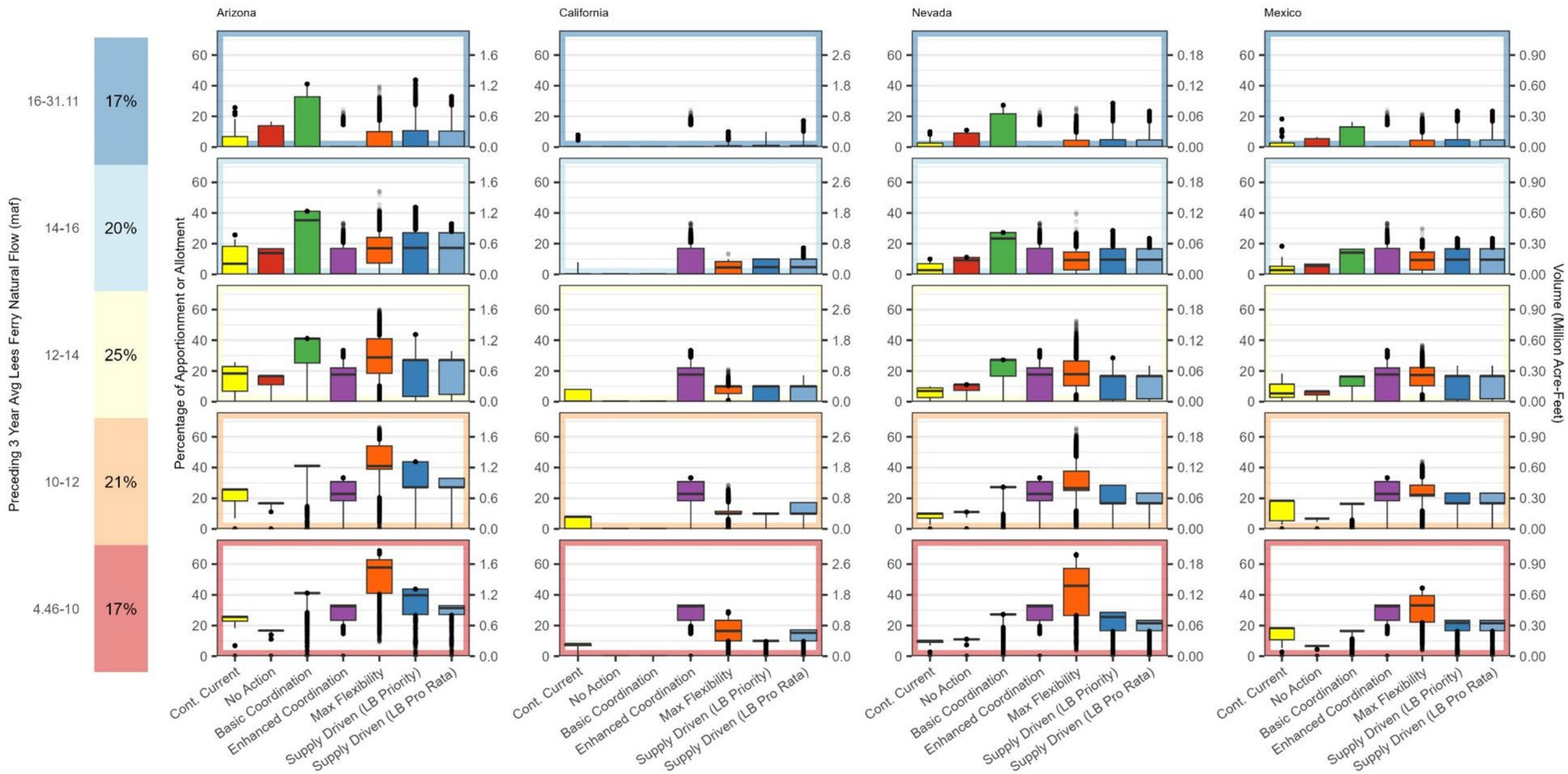
Shortage by State

Shortage under different hydrologic conditions categorized by the preceding 3-year average of Lees Ferry natural flow is compared across alternatives in **Figure 3-15**. There is a column for each Lower Basin state and Mexico. The vertical axis for each state's column is scaled based on its respective volume of apportionment; the percent apportionment is shown on the left side of each column, and the absolute volume of shortage is shown on the right. A summary by state for Arizona, California, and Nevada follows.

Arizona

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortage occurs under the Maximum Operational Flexibility Alternative (57.8 percent of apportionment), and the lowest median shortage occurs under the No Action Alternative (16.7 percent of apportionment). The full range of shortages across the different alternatives can be viewed in **Figure TA 4-8** in **TA 4**, Water Deliveries. Arizona Priority 4 users make up the largest volume of Arizona's apportionment and experience the largest shortages compared to other priority users. Shortage is also displayed by priority in **Figure TA 4-9** in **TA-4**, Water Deliveries.

Figure 3-15
Calendar Year Shortage by State and Water Delivery Reductions to Mexico



Note: The modeled annual delivery reductions in Mexico include modeling assumptions for reductions in water deliveries to Mexico and storage available to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current United States policy or a determination of future United States policy regarding deliveries to Mexico. The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

California

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortage occurs under the Enhanced Coordination Alternative (32.6 percent of apportionment) and the lowest non-zero median shortage occurs under the Supply Driven Alternative with the LB Priority approach (10 percent of apportionment). The CCS Comparative Baseline and the No Action and Basic Coordination Alternatives, all priority-based, do not impose shortages on any users (regardless of priority) in California. The Enhanced Coordination Alternative and Supply Driven Alternative with the LB Pro Rata approach distribute shortages pro rata and are therefore the only alternatives that apply shortages to California's high priority users (PPRs, Priority 1 and Priority 2), with the exception of some high outlier shortages for Priority 1 and Priority 2 users under the Maximum Operational Flexibility Alternative in the drier flow categories. The full range of shortages across the different alternatives can be viewed in **Figure TA 4-8** in **TA-4**, Water Deliveries. Shortage is also displayed by priority in **Figure TA 4-10** in **TA-4**, Water Deliveries.

Nevada

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortage occurs under the Maximum Operational Flexibility Alternative (45.9 percent of apportionment), and the lowest median shortage occurs under the No Action Alternative (11 percent of apportionment). Except for the Enhanced Coordination Alternative and the Supply Driven Alternative (LB Pro Rata approach), all alternatives and CCS Comparative Baseline use the priority system to partially or fully distribute shortage. As a result, only the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives impose shortages on higher priority users (those that represent a small fraction of Nevada's apportionment). The full range of shortages across the different alternatives can be viewed in **Figure TA 4-8** in **TA-4**, Water Deliveries. Shortage is also displayed by priority in **Figure TA 4-11** in **TA-4**, Water Deliveries.

Annual Depletions

Depletion (also referred to as total consumptive use or the net amount of water used) is defined as the amount of water diverted from the river minus the return flow. Return flow is the portion of water diverted for use that is not used and ultimately returned to the river for subsequent use downstream. For all entities and across all alternatives and the CCS Comparative Baseline, median depletions decrease as flow categories become drier, and an increasing number of years are affected by dead pool.

Arizona

In the Critically Dry Flow Category (4.46–10.0 maf), median depletions are lowest under the Maximum Operational Flexibility Alternative (42 percent of apportionment, 1.2 maf). The Enhanced Coordination Alternative has the highest median depletions at 71.3 percent of apportionment (2.0 maf), due to the pro rata distribution. The full range of annual depletions in Arizona across the different alternatives can be viewed in **Figure TA 4-12** in **TA-4**, Water Deliveries.

California

In the Critically Dry Flow Category (4.46–10.0 maf), the Enhanced Coordination Alternative has the lowest median depletion (67 percent of apportionment, 2.9 maf). The Basic Coordination

Alternative has the highest median depletion (100 percent of apportionment, 4.4 maf). The full range of annual depletions in California across the different alternatives can be viewed in **Figure TA 4-13** in **TA-4**, Water Deliveries.

Nevada

In the Critically Dry Flow Category (4.46–10.0 maf), median depletions are lowest for the No Action Alternative (64 percent of apportionment, 0.19 maf). The Supply Driven Alternative (LB Pro Rata approach) has the highest median depletion (96.4 percent of apportionment, 0.29 maf). The full range of annual depletions in Nevada across the different alternatives can be viewed in F**igure TA 4-14** in **TA-4**, Water Deliveries.

Surplus

Surplus deliveries become more frequent as flow conditions become wetter. In the Average Flow Category (12.0–14.0 maf), the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) shows the highest surplus frequency at about 18 percent of years, while all other alternatives and the CCS Comparative Baseline remain below 10 percent. In the Wet Flow Category (16–31.11 maf), surplus occurs in more than 60 percent of years under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), compared to 36–52 percent for other action alternatives and the CCS Comparative Baseline. The No Action Alternative has the lowest surplus frequency, around 30 percent of years in wet conditions. The full range of frequency of surplus across the different alternatives can be viewed in **Figure TA 4-15** in **TA-4**, Water Deliveries.

Issue 4: Deliveries to Mexico

Issue 4 addresses how operational activities affect deliveries to Mexico. Refer to **TA- 4**, Water Deliveries for greater details regarding the analysis of impacts as well as **Appendix M**, International Border Region of the Colorado River for additional information regarding water deliveries to the International Border Region.

Annual Reductions

Reductions in water deliveries to Mexico generally increase as flow conditions become drier. Variability narrows for the CCS Comparative Baseline and all action alternatives except the Maximum Operational Flexibility Alternative. The Maximum Operational Flexibility Alternative shows the opposite trend, with variability increasing under drier conditions. In the Critically Dry Flow Category (4.46–10.0 maf), all alternatives reach their maximum shortage levels, with Enhanced Coordination and Maximum Operational Flexibility Alternatives exhibiting the highest potential reductions. Refer to tables and figures in **TA-4-**Water Deliveries for further information.

Annual Depletions

Median depletions, as a percentage of allotment, decline across all action alternatives as the flow conditions become drier. In the Average Flow Category (12.0–14.0 maf), the interquartile ranges for all alternatives are below 100 percent of allotment. The median for all action alternatives is around 79–83 percent of allotment (1.18–1.25 maf) compared to 91.5 percent of allotment in the CCS Comparative Baseline and the No Action Alternative. In the Critically Dry Flow Category (4.46–10.0 maf), median allotments for the action alternatives range from as low as 66 percent (0.99 maf) under the Maximum Operational Flexibility Alternative, up to 84 percent (1.25 maf) under the Basic

Coordination Alternative. Refer to tables and figures in **TA-4**, Water Deliveries for further information.

Issue 5: Lower Division States Combined Shortages

Issue 5 addresses how operational activities affect modeled distribution of combined shortages for the Lower Division states. As discussed in Chapter 2, the alternatives considered evaluate a distribution of shortages via priority and pro rata. Lower Division states' shortage distributions discussed under this issue were modeled with the SAMs and ADMs to estimate the volume of available water to entitlement holders or water users under Shortage Conditions over a specified range of shortage volumes. Refer to **TA-4**, Water Deliveries for greater details regarding the analysis of impacts as well as the **Appendix C,** Shortage Allocation Model and Alternative Distribution Model Documentation for additional information.

Tribal, Domestic, and Irrigation Shortage Impacts

For tribal users, priority-based alternatives impose larger shortage impacts than pro rata when comparing the same total shortage volume. Total shortage impacts range from 76 kaf to 582 kaf across all alternatives and the CCS Comparative Baseline.

For domestic users, the priority-based alternatives impose larger shortage impacts than pro rata when comparing the same total shortage volume. Total shortage impacts range from 109 kaf to 1,501 kaf across all alternatives and the CCS Comparative Baseline.

For irrigation users, the pro rata–based alternatives impose larger shortage impacts than priority alternatives when comparing the same total shortage volume. Total shortage impacts range from 2 kaf to 1,578 kaf across all alternatives and the CCS Comparative Baseline.

Volumes of Shortage by State (Arizona, California, Nevada)

State specific distribution of shortages can be viewed in **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation.

Issue 6: Upper Basin Conservation

This section describes how different alternatives perform in terms of annual Upper Basin conservation activity. **Figure 3-16** shows three components of Upper Basin Conservation activity.[10] The first column shows the annual, total volume of conserved water accumulated by Upper Basin conservation. The second column reports the annual volume of conserved water that is created. The third column reports the annual volume that is converted to system water.

There is zero accumulation, creation, or conversion under the CCS Comparative Baseline or the No Action and Basic Coordination Alternatives, so the remainder of the discussion on **Figure 3-16** focuses on Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches).[11]

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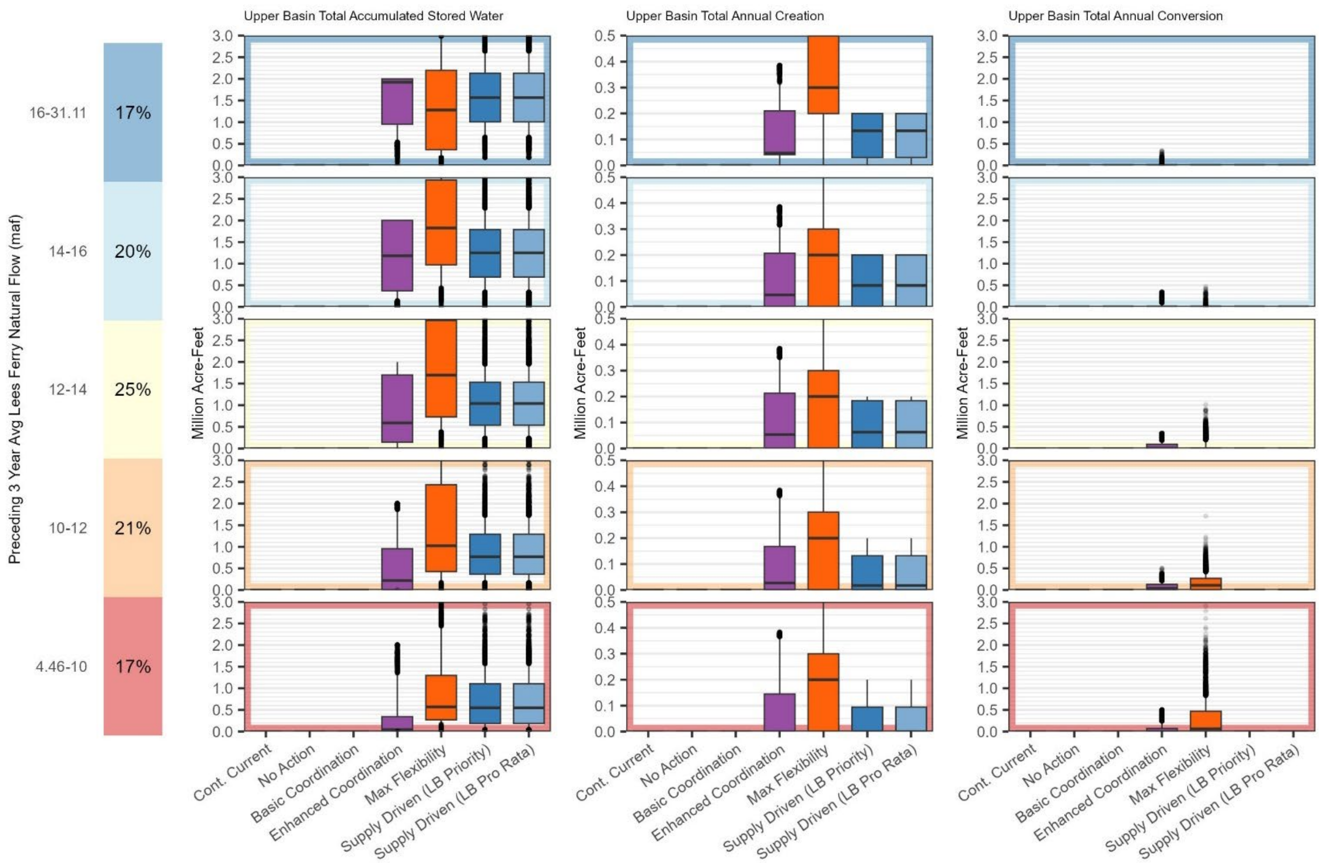
[10] For all alternatives except Maximum Operational Flexibility, Lower Basin conserved water is stored in Lake Powell. For Maximum Operational Flexibility, this water can be stored in Lake Mead, Lake Powell, or both.

[11] UB conservation activity is the same for both Supply Driven (LB Priority) and Supply Driven (LB Pro Rata).

Figure 3-16
Annual Upper Basin Conservation Activity



Note: In addition to the conservation volumes, the Supply Driven alternative also includes "gap water" (see **Section 2.8.4.3** and **Appendix A,** CRSS Model Documentation). The modeled gap water volume has a median of 0 in all flow categories; the 75*th* percentile is approximately 256 kaf and 358 kaf in the dry and critically dry flow categories, respectively; the maximum gap water volume is approximately 1.1 maf. **Appendix D**, Sensitivity Analysis – Effects of Natural Flow Percentage Used for the Supply Driven Alternative, includes additional information on the modeled volumes of gap water.

Considering total annual accumulation (first column), under the Average Flow Category (12-14 maf), the Maximum Operational Flexibility Alternative has the largest median (1.7 maf), followed by the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches; 1.0 maf) and the Enhanced Coordination Alternative (0.59 maf). The relative ranking is the same under the Critically Dry Flow Category (4.46-10 maf), with medians of 0.57 maf (Maximum Operational Flexibility Alternative), 0.55 maf (Supply Driven Alternative [both LB Priority and LB Pro Rata approaches]), and 0.045 maf (Enhanced Coordination Alternative).

Considering total annual creation (second column), under the Average Flow Category, the Maximum Operational Flexibility Alternative has the largest median (200 kaf), followed by Supply Driven Alternative (both LB Priority and LB Pro Rata approaches; 63 kaf) and Enhanced Coordination Alternative (53 kaf). Under the Critically Dry Flow Category, the median for the Maximum Operational Flexibility Alternative remains at 200 kaf, but the median is 0 for both Enhanced

Coordination and Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches). However, the 75th percentiles are 300 kaf (Maximum Operational Flexibility Alternative), 140 kaf (Enhanced Coordination Alternative), and 94 kaf (Supply Driven Alternative [both LB Priority and LB Pro Rata approaches]).

Considering total annual conversion (third column), the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) does not convert any conserved water (i.e., values of 0 for all flow categories and all percentiles). For Maximum Operational Flexibility and Enhanced Coordination Alternatives, the largest conversion volumes occur in Dry (10-12 maf) to Critically Dry Flow Categories (4.46-10 maf). Because conversion happens relatively infrequently and at small volumes, it is useful to compare the 75th percentile values. In the Dry Flow Category, 75th percentile conversion volumes are 270 kaf (Maximum Operational Flexibility Alternative) and 130 kaf (Enhanced Coordination Alternative). Under the Critically Dry Flow Category, the 75th percentile values are 470 kaf (Maximum Operational Flexibility Alternative) and 69 kaf (Enhanced Coordination Alternative).

Summary Comparison of Alternatives

All alternatives and the CCS Comparative Baseline differ in how they impact shortages, dead pool–related reductions, depletions, and surplus. Tradeoffs exist between shortages, dead pool–related reductions, depletions, and water shortage impacts and are further discussed below.

Shortage versus Dead Pool–Related Reductions

Generally, higher shortages correspond to lower frequency and smaller volumes of dead pool–related reductions. In most cases, more aggressive shortage policies can improve system robustness. The Maximum Operational Flexibility Alternative demonstrates this most strongly, avoiding dead pool–related reductions in 91 percent of futures but imposing the highest shortage (4 maf). Conversely, the No Action Alternative applies the smallest shortage (0.6 maf) yet is the least robust, avoiding dead pool–related reductions in only 30 percent of futures.

Shortage versus Depletions by State and Mexico

Shortage and depletion patterns vary by state and Mexico, in opposite directions.

Arizona

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortages occur under the Maximum Operational Flexibility Alternative (57.8 percent of apportionment), and the No Action Alternative has the lowest (16.7 percent of apportionment). However, the highest median depletions occur in the Enhanced Coordination Alternative (71.3 percent of apportionment) and lowest median occurs in the Maximum Operational Flexibility Alternative (42.5 percent of apportionment). In this case, high shortage correlates to low depletions but low shortage still results in low depletions. However, the Supply Driven Alternative (Pro Rata approach) has the second lowest median shortage (31.4 percent of apportionment) but the second highest median depletion at 63 percent of apportionment.

California

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortage occurs under the Enhanced Coordination Alternative (32.6 percent of apportionment) followed by the Maximum Operational Flexibility Alternative (16.4 percent of apportionment), and the Basic Coordination and No Action Alternatives have the lowest (0 percent of apportionment). Highest median depletions occur under the Basic Coordination Alternative (100 percent of apportionment), CCS Comparative Baseline (92 percent of apportionment), and No Action Alternative (89 percent of apportionment), whereas the lowest median depletions occur under the Enhanced Coordination (66.6 percent of apportionment) and Maximum Operational Flexibility Alternatives (82 percent of apportionment). For California, high shortage typically results in lower depletions and vice versa.

Nevada

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortage occurs under the Maximum Operational Flexibility Alternative (45.9 percent of apportionment), and the No Action Alternative and CCS Comparative Baseline have the lowest (11 percent and 10 percent of apportionment, respectively). The highest median depletions occur under Supply Driven Alternative Pro Rata approach (91.9 percent of apportionment) and lowest median under the No Action Alternative (64.2 percent of apportionment). For Nevada, the lower shortage occurs with lowest depletions.

Mexico

In the Critically Dry Flow Category (4.46–10.0 maf), the highest median shortage occurs under the Maximum Operational Flexibility Alternative (33.1 percent of apportionment) and lowest median under the No Action Alternative (6.7 percent of apportionment). The lowest median depletions occur under the Maximum Operational Flexibility Alternative at 66.1 percent of apportionment and the highest median under the Basic Coordination Alternative (83.6 percent of apportionment). For Mexico, higher shortage typically results in lower depletions.

Water User Shortage Impacts

Shortage impacts vary in magnitude and by user. For tribal and domestic users, priority-based alternatives impose larger shortage impacts than the pro rata alternatives. Further discussion is included in **TA 17**, Population and Land Use and **TA 18**, Indian Trust Assets. For irrigation users, the pro rata–based alternatives impose larger shortage impacts than priority alternatives when comparing the same total shortage volume, further discussion is included in **TA 17**, Population and Land Use.

3.5 Geomorphology and Sediment

3.5.1 Affected Environment

This section describes how sediment and geomorphic processes shape the Colorado River below Glen Canyon Dam. Sandbars and channel-margin deposits depend on the river's sediment mass balance—the difference between the sediment entering and leaving the system. Before Glen Canyon Dam was built, the river carried large amounts of suspended sediment year-round. After the dam's completion, about 95 percent of the historical sediment supply from the Upper Basin was cut off, leaving the river with a long-term sediment deficit (Topping et al. 2000). As a result, the river now erodes sandbars and channel deposits faster than tributaries can replace them. Since the 1960s, most years have shown net erosion in Marble and Grand Canyons (Topping et al. 2021).

Dam operations also influence sediment behavior. Today's managed flows are much lower and more stable than historical floods, and minimum flows remain above levels that once allowed seasonal sand accumulation. Combined with the reduced sediment supply, these regulated discharges limit sand deposition, shorten the time available for sand storage, and increase erosion of beaches and sandbars (USGS 2011).

Downstream of Glen Canyon Dam, the Paria and Little Colorado Rivers are the dominant sediment sources. Upstream of the Paria, modern Glen Canyon receives little sediment input, making its sediment effectively nonrenewable (Grams et al. 2007). Sand delivered from tributaries tends to remain in the system only for a few months unless flows remain below roughly 9,000 cfs (Topping et al. 2000; Rubin et al. 2002; USGS 2011). Most sediment ultimately continues downstream toward Lake Mead.

Fine sediment—sand, silt, and clay—is the primary material transported by the river and the main contributor to sandbar formation. Sand stored on the riverbed supplies the material that forms sandbars during high flows. Sediment transport increases with flow volume, turbulence, and changes in sediment size delivered by tributary floods. Deposition occurs in low-velocity environments such as recirculation zones of eddies and along channel margins, and storage varies with riverbed topography and tributary activity.

Geomorphically, the river consists of long pools separated by steep rapids formed at debris-fan deposits left by tributary debris flows. These fans constrict the channel, generate rapids, and create recirculating eddies where sandbars form (**Figure TA 5-1** in **TA 5**, Geomorphology and Sediment). Most Grand Canyon sandbars are tied to these fan-eddy complexes and remain dynamic features that continually exchange sand with the river. Sandbars provide key ecological, cultural, and recreational functions, supporting habitat, vegetation, archaeological resource protection, and camping areas along the river (Rubin et al. 2002; Mueller et al. 2018; Hazel et al. 2022; Reclamation 2024b).

To counteract long-term sandbar erosion, Reclamation conducts HFEs that release large, short-duration floods from Glen Canyon Dam. HFEs are the only mechanism capable of producing water stages high enough to rebuild sandbars. Bar size generally increases during HFEs and then diminishes between them, with erosion highest immediately after floods. More frequent HFEs can increase sandbar size if sufficient sand is available (Grams et al. 2025).

3.5.2 Environmental Consequences

Methodology

All modeling used for this resource section was based on modeling performed by the USGS, GCMRC (Grams et al. 2025; Salter et al. 2025), and developed using the CRSS hydrological modeling results. Tributary sediment inputs from the Paria and Little Colorado Rivers were generated using the Wright et al. (2010) model. Outputs fed the Mueller and Grams (2021) sandbar model, recalibrated to the 2002–2024 period, based on the long-term monitoring program, and initialized using the January 1, 2025, volume (1169.5 cubic meters). The model ran each alternative for all 400 traces and 3 initial conditions. Some modifications were made to the Mueller and Grams (2021) sandbar model to include additional sandbars in the calibration dataset, incorporate discharge-dependence into the erosion model, and assume a constant sandbar area (Salter et al. 2025). Two versions of the sandbar model were used to predict sandbar deposition: one for flow rates exceeding 8,000 cfs, the average daily discharge flow; and one for flow rates exceeding 25,000 cfs, the discharge at which sandbars will not be inundated during normal dam operations and will result in usable sandbars for recreational purposes (Salter et al. 2025). Except for modeled HFEs, the sandbar model did not include any sustained releases above 25,000 cfs over the calibration period. See **Section TA 5.2.1**, Methodology, in **TA-5**, Geomorphology and Sediment Resources, for additional information.

Impact Analysis Area

The impact analysis area used for GCMRC sediment modeling data extends from the Colorado River at Glen Canyon Dam to Lake Mead, including sediment inputs from the Paria and Little Colorado River tributaries. The analysis area for the sandbar model (quantitative model) is from Lees Ferry (RM 0 through Diamond Creek [RM 225]). The extent of this model is limited by the availability of study sites in the calibration dataset. However, it is expected that the findings for the reach between Lees Ferry and Diamond Creek are also representative for similar sandbars downstream to Separation Canyon (RM 240), the full-pool extent of Lake Mead. With low Lake Mead elevations, the Colorado River will cut new paths through the deltas at its mouth in the reservoir. This will result in sediment redistribution in the reservoir for which no model is currently available. This redistribution of sediment will form new bars and alter the delta. Finer particles may remain in suspension and travel further downstream in the reservoir before settling, increasing sediment concentration near the upper reaches of Lake Mead.

The proposed alternatives may modify the magnitude, timing, or variability of releases from Hoover Dam relative to existing operations. Any such changes would affect sediment resources downstream by altering sediment transport capacity and the degree to which available fine sediment is mobilized or retained. However, because the downstream reach is sediment-starved and the alternatives would not change Hoover Dam operations, introduce new sources of sediment or significantly modify sediment supply, or change channel morphology, any effects on geomorphology and sedimentation downstream of Hoover Dam are expected to be negligible.

Assumptions

- HFEs require sufficient sand in Marble Canyon (positive sand mass balance) and adequate Lake Powell water levels, both dependent on the chosen HFE duration.
- HFE releases can only be implemented above a 3,500-foot Lake Powell elevation, the elevation required for a release magnitude of 37,000 cfs (Reclamation 2024b; Salter et al. 2025).
- Non-HFE flows can deposit sand, but only sand deposited during flows above 25,000 cfs is considered usable for recreation.

- Sandbar building is fastest during the first 4 days; a 60-hour HFE produces strong deposition while allowing more frequent events and reducing interim erosion.
- Maximum ramp rates (4,000 cfs up / 2,500 cfs down per hour) are in accordance with 2016 and 2024 LTEMP guidelines.
- Most of the sand input from the Paria and Little Colorado Rivers occurs during the summer-fall thunderstorm season between July 1 and November 1.
- If no HFE releases were implemented during the 1-year sediment accounting period, any positive sediment balance would be carried forward to the next accounting period.

Impact Indicators

Issues related to geomorphology and sedimentation that are evaluated in this section are listed below. Each of the five issues is associated with one or two "indicators," which serve as preferred minimum performance against which the issues are compared for the purpose of this analysis.

1. Water Availability in Lake Powell
2. Sand Mass
3. HFE Frequency and Duration
4. Sandbar Volume
5. Sand Transport

Issue 1: Water Availability

An HFE likely to enlarge sandbars requires enough water for a release magnitude of 37,000 cfs. A release rate of 37,000 cfs, in turn, requires a minimum Lake Powell water level of 3,500 feet in April or November, the months in which HFEs typically occur. Alternatives that more frequently result in water levels greater than this threshold are therefore deemed preferable.

It should be noted that there are known issues that may present challenges for conducting HFEs at the minimum Lake Powell elevation of 3,500 feet. Historically, the lowest elevation at which an HFE has been implemented was approximately 3,523 feet in April 2023. Since the models used elevation of 3,523 and lower as the possible elevations at which HFEs could occur, it is therefore likely that modeling overestimates the number or frequency of HFEs. **Table TA 5-1** shows the percentage of modeled HFEs by alternative that were above (or below) this lowest historical elevation.

Figure TA 5-2 in **TA 5**, Geomorphology and Sediment, shows the percentage of simulated years for which Lake Powell elevation is greater than 3,500 feet in November or April. The highlighted row indicates the percentage of futures that meet this condition for all years in the simulation period (i.e., 100 percent of the simulation period), the preferred minimum performance. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust by a wide margin, meeting the preferred minimum performance in 87 percent and 91 percent of futures, respectively. **Figure TA 5-3** in **TA 5**, Geomorphology and Sediment, shows the same information as **Figure TA 5-2** but for an elevation threshold of 3,523 feet, the lowest Lake Powell elevation in the historical record. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are still the most robust with the 3,523-foot threshold; however, the percentage of futures that meet the preferred minimum performance (63 percent and 51 percent, respectively) is lower than for the 3,500-foot threshold. **Figure TA 5-4** in **TA 5**, Geomorphology and Sediment, also demonstrates that these two alternatives would be the least vulnerable with respect to water availability.

Issue 2: Sand Mass

The second condition required for an HFE release is the availability of sand. Sand that accumulates in Marble Canyon and is transported downstream outside HFE events does not result in sandbar formation. While the proposed alternatives would not impact the inflow of sand from the Paria River and Little Colorado River, they would affect the timing and magnitude of releases outside HFE releases and, therefore, impact sand and sand transport that occurs outside these events.

Glen Canyon Dam releases for hydropower generation tend to be high in July and August (Reclamation 2016). This period also coincides with the summer-fall thunderstorm season in the Paria and Little Colorado watersheds that causes sand to be transported to Marble Canyon. Sand tends to accumulate during September and October because the reduced releases are not enough to transport the sand downstream. Unless it is a particularly dry year, flows increase during the winter months, resulting in the transport of increasing quantities of sediment downstream.

While average flows must be lower than about 11,000 cfs to allow sediment accumulation under most initial conditions, flows greater than 15,000 cfs are likely to be erosive regardless of those initial conditions (Salter et al. 2025). Therefore, futures with flows less than 900,000 af per month (i.e., non-erosive flows) for at least 90 percent of a simulation period are considered preferable. As detailed in **Figure TA 5-5** in **TA 5**, Geomorphology and Sediment, the Enhanced Coordination Alternative meets this condition in 59 percent of simulated futures, while none of the other alternatives meet this condition in at least 28 percent of simulated futures.

Historical data indicate that sandbar deposition typically occurs at HFE durations of 60 hours or greater (Grams et al. 2025). **Figure TA 5-8** in **TA 5**, Geomorphology and Sediment, shows the frequency at which the sand mass in Marble Canyon exceeds 294,000 metric tons, the average transport capacity for a 60-hour event, in November or April. The highlighted row indicates the percentage of futures that meet this condition at least once every 4 years, the preferred minimum performance. Aside from the CCS Comparative Baseline, the percentage of futures in which November or April sand mass exceeds 294,000 metric tons at least every 4 years is comparable across the alternatives, ranging from 43 percent to 47 percent for the full modeling period. All alternatives perform better during each of the three subperiods, reflecting a significant variability in interdecadal hydrologic conditions over the simulation period.

Issue 3: HFE Frequency and Duration

To allow for sandbar deposition that is sufficient to at least partially compensate for natural erosion in between HFEs, futures are considered preferable if they predict a spring or fall HFE of 60 hours or greater at least once every 4 years.

As shown in **Figure TA 5-9** in **TA 5**, Geomorphology and Sediment, for the full modeling period, none of the alternatives meet this condition in more than 25 percent of simulated futures, suggesting the dependence of this metric on the availability of sand, given the high percentage with which the Maximum Operational Flexibility and Enhanced Coordination Alternatives result in enough water for an HFE release (**Figure TA 5-2**). The alternatives perform better during each of the three subperiods, with the Maximum Operational Flexibility and Enhanced Coordination Alternatives once again performing the best. **Figure TA 5-10** in **TA 5**, Geomorphology and Sediment, also shows that the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform the best for HFE releases lasting 12 to 96 hours, with 46 percent and 43 percent of years having HFE releases greater than or equal to 60 hours, respectively. This performance is notable because, excluding the HFE implemented on March 26, 1996, only HFEs between 60 and 96 hours have been implemented (Grams et al. 2025).

Figure TA 5-11 in **TA 5**, Geomorphology and Sediment, shows the distribution of HFE durations for the full sediment year (July 1 to July 1), fall, and spring. The distributions are further categorized into five hydrologic conditions based on the average natural flow rates at Lees Ferry over the preceding 3-year period. The figure illustrates a shift from fall HFE releases to spring HFE releases as the preceding 3-year average Lees Ferry natural flow decreases (i.e., conditions become drier). For the Critically Dry Flow Category (4.46–10.0 maf), only the Maximum Operational Flexibility and Enhanced Coordination Alternatives result in HFE durations of any substantial duration, typically occurring in the spring, when snowpack is known and inflow volumes can be more easily predicted.

Issue 4: Sandbar Volume

In the context of sediment, the ultimate measure of an alternative's performance is the volume of "usable" sand in the canyon; that is, the sandbar volume above the water level during a 25,000 cfs flow condition, the threshold above which camping and recreational activities are considered safe from flooding. As shown in **Figure TA 5-12** in **TA 5**, Geomorphology and Sediment, sandbar growth generally increases as hydrologic conditions become drier, and the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform the best in the Critically Dry Flow Category (4.46–10.0 maf).

Futures are considered preferable if net sandbar volumes exceed the sandbar volumes at the start of the simulation for 60 percent or more of the simulation period. As detailed in **Figure TA 5-13** in **TA 5**, Geomorphology and Sediment, the action alternatives perform well for this issue; at least 90 percent of futures have larger sandbar volumes than at the start of the simulation period for at least 60 percent of the simulation period. Even the CCS Comparative Baseline results in the preferred minimum performance for 72 percent of futures. For reference, the sandbar volume at the start of the simulation period is approximately 1,170 cubic meters (41,300 cubic feet).

Figure TA 5-14 in **TA 5**, Geomorphology and Sediment, shows this issue from a different perspective, providing the percentage of simulated years for which the maximum sandbar volume is less than or equal to a given value. A lower percentage of years for which sandbar volume is below a given value corresponds to a greater percentage of years for which sandbar volume is above that value. Therefore, curves with lower placement in the plot imply better performance for that alternative. While the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) results in the best performance, differences among the alternatives are minimal.

Issue 5: Sand Transport

While sand can be transported downstream with flows well below 37,000 cfs, lower flows are not conducive to sandbar formation and retention. The higher the fraction of sand transported above 37,000 cfs, the more sand will be available for sandbar formation (Hazel et al. 2022; Salter 2025).

Figure TA 5-15 in **TA 5**, Geomorphology and Sediment, shows the percentage of futures for which the total sand mass transported by flow rates above 37,000 cfs (sandbar-forming flow rates) exceeds a given fraction over the 34-year simulation period. Futures are considered preferable if the fraction of sand mass transported by sandbar-forming flow rates is at least 0.4 (40 percent of the sand transport). The highlighted row provides the percentage of futures that meet this criterion. Under the Maximum Operational Flexibility and Enhanced Coordination Alternatives, 82 percent of simulated futures are considered preferable—that is, at least 40 percent of sand mass is transported by sandbar-forming flow rates in 82 percent of simulated futures. Performance for the Basic Coordination and the Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are similar, with 77 percent and 74 percent of futures considered preferable, respectively.

Summary Comparison of Alternatives

Taken as a whole, the results of the analysis suggest that the Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with respect to geomorphology and sediment. This appears to be largely due to their superior ability to affect Lake Powell water levels exceeding 3,500 feet in November and April, one of two conditions required for an HFE release (**Figure TA 5-2** in **TA 5**, Geomorphology and Sediment). The impacts on sand mass in Marble Canyon, the other condition required for an HFE release, under the Maximum Operational Flexibility and Enhanced Coordination Alternatives are comparable to the other alternatives, including the CCS Comparative Baseline (**Figure TA 5-7** in **TA 5**, Geomorphology and Sediment). During the driest climatic conditions (for which the preceding 3-year average Lees Ferry natural flow is less than 10.0 maf), these two are the only alternatives that would result in HFEs of any substantial duration, typically occurring in the spring.

3.6 Water Quality

3.6.1 Affected Environment

Salinity

The Colorado River Basin Salinity Control Forum reviews and makes salinity criteria recommendations for the Colorado River every 3 years. Flow-weighted average annual salinity criteria for the Colorado River are currently 723 milligrams per liter (mg/L) below Hoover Dam, 747 mg/L below Parker Dam, and 879 mg/L at Imperial Dam (Colorado River Basin Salinity Control Forum 2023).

Salinity control is accomplished through multiple programs. Federal agencies, including Reclamation, the BLM, and the U.S. Department of Agriculture, pursue improvements on federal lands to reduce salinity loading to the Colorado River (Reclamation 2022). Since the construction of Glen Canyon Dam, annual salinity concentrations downstream of Glen Canyon Dam have varied between 400 and 600 mg/L (Richards 2025). In a review of sampling efforts from 2007–2023, Reclamation has not exceeded the salinity criteria for the Colorado River. See **Section TA 6.1.1**, Salinity, in **TA 6**, Water Quality, for more information on salinity in the planning area and historical salinity concentrations in the Lower Basin.

Temperature

Lake Powell is a monomictic[12] reservoir with strong thermal stratification through much of the spring, summer, and early fall; this means the water is layered, with distinct temperatures and chemical characteristics. Generally, Lake Powell's epilimnion, or uppermost layer, ranges from 25 to 30 degrees Celsius (°C; 77 to 86 degrees Fahrenheit [°F]) in the summer, dropping to 6 to 10 °C (42.8 to 50 °F) in the winter (Deemer et al. 2023). Lake Powell's hypolimnion, or deeper layer, ranges from 6 to 9 °C (42.8 to 48.2 °F) year-round. Since the early 2000s, lower water levels in Lake Powell have led to warmer summer water temperatures in the Colorado River below Glen Canyon Dam (Reclamation and NPS 2016). Temperatures in the Colorado River in the Grand Canyon vary widely over space and time and are primarily controlled by the discharge and temperature released from Glen Canyon Dam and solar radiation dynamics along the river corridor (Mihalevich et al. 2020).

Lake Mead is also monomictic. Lake Mead inflow temperatures are a function of Glen Canyon Dam discharges and downstream weather conditions (Reclamation and NPS 2016). Lake Mead's hypolimnion is around 12 °C (53.6 °F) year-round. Its epilimnion ranges from about 14 to 29 °C (57.2 to 84.2 °F) in the spring, summer, and early fall, and drops to about 13 to 15 °C (55.4 to 59 °F) in the winter (SNWA 2023). Further declines in reservoir elevation, coupled with rising air temperatures, may continue to lead to warmer releases from Lake Mead, though this depends on whether the lower Hoover Dam outlet is used (Hannoun 2022).

Harmful Algal Blooms and Nutrients

Nutrients, such as nitrogen and phosphorus, are essential for life, but excess nutrients in water can harm human health and ecosystems and impact recreational opportunities (USGS 2019a; NPS 2025a). The most severe algal blooms are caused by cyanobacteria, which can produce toxins that can threaten drinking water quality and harm human health (USGS 2019a). In Lake Mead, water within Las Vegas Bay has the highest concentration of nutrients due to discharges of highly treated wastewater from the Las Vegas metropolitan area. Wastewater is a persistent contributor of phosphorus, whereas stormwater with higher phosphorus contributions is an acute contributor but a minor source overall. This is because storm events are infrequent. Since phosphorus is a limiting nutrient in the Colorado River system, these contributions support algal growth (USGS 2012). Lowering reservoir levels could increase the concentration of nutrients and temperatures, especially in shallow areas, which could be more favorable for algal growth (Hannoun et al. 2022).

Dissolved Oxygen

Dissolved oxygen is a critical factor for fish health. Research on dissolved oxygen thresholds for both warmwater and cold-water fish species shows that salmonids are particularly vulnerable to low dissolved oxygen concentrations compared with warmwater species (Saari 2018). Sustained dissolved

[12] Monomictic waterbodies are those that mix completely during one mixing period each year.

oxygen levels below 3 mg/L can significantly reduce survival rates and feeding efficiency, whereas concentrations in the range of 6 to 9 mg/L are considered optimal for growth and survival across all life stages (EPA 1986).

Generally, Lake Powell's dissolved oxygen concentrations are at their highest in the spring to early summer, when inflows are well oxygenated and wind-induced mixing is high. Low dissolved oxygen concentrations move through the reservoir and closer to the dam during the summer into the fall because of organic matter decomposition and chemical reactions that consume oxygen. Dissolved oxygen gradually increases in the winter as a result of the higher oxygen-carrying capacity of cold water and the natural mixing during turnover. When water is discharged through the river outlet works, it becomes well aerated and increases the dissolved oxygen levels in the tailwaters, but only while the river outlet works are open.

Recently, dissolved oxygen levels in Lake Powell and the Glen Canyon Dam tailwaters[13] have been low compared with historical dissolved oxygen levels. This is due to low reservoir elevations and the increasing reservoir age (Deemer et al. 2025). Dissolved oxygen levels below Glen Canyon Dam vary throughout the year, falling as low as 2.2 mg/L in the summer and rising as high as 9 to 10 mg/L in the spring (GCMRC 2025). Dissolved oxygen increases approximately 1 mg/L between Glen Canyon Dam and Lees Ferry. Low dissolved oxygen conditions improve downstream of the Paria Riffle and Badger Rapids as the water is reaerated through whitewater action.

In Lake Mead, dissolved oxygen levels decrease in the bottom of Las Vegas Bay as a result of high decomposition of organic matter from the Las Vegas Wash. When there are greater nutrients in surface water, generally more decomposition and low oxygen occur in bottom waters. Monitoring is ongoing to determine the cause of decreased dissolved oxygen concentrations in isolated areas, but the driver is likely higher temperatures from inflows (Reclamation and NPS 2016).

Metals, Perchlorate, and Per- and Polyfluoroalkyl Substances

The planning area contains sources of metals and regulated chemicals, including perchlorate and per- and polyfluoroalkyl substances (PFAS), although metals and perchlorate are not a typical concern. Generally, as reservoir elevations decrease, the dilution capacity of reservoirs like Lake Powell and Lake Mead would also decrease. Decreased dilution capacity from lower reservoir elevations could result in greater concentrations of pollutants of concern, such as PFAS. For more information, see **Sections TA 6.1.5**, Metals; **TA 6.1.6**, Perchlorate; and **TA 6.1.7**, PFAS, in **TA 6**, Water Quality.

3.6.2 Environmental Consequences

Methodology

The analysis methodology for water quality is based on a combination of DMDU; CRSS; GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry, and Grand Canyon; SNWA's Lake Mead Model; SNWA's Machine Learning Model; and qualitative analysis. For detailed

[13] Tailwater refers to waters located immediately below the dam. It is the reach of river immediately downstream of a reservoir that is heavily influenced by reservoir characteristics. Tailwaters are generally expected to have water quality that is more similar to the water quality in reservoirs compared with reaches farther downstream.

information on the dissolved oxygen and water temperature models, see **Section TA 6.2.1**, Methodology, in **TA 6**, Water Quality, for more information.

The CRSS model simulates Colorado River Basin conditions decades into the future and can account for hydrologic uncertainty. The CRSS model is a monthly time-step model that produces reservoir elevations, dam releases, and salinity concentrations. Refer to **Appendix A**, CRSS Model Documentation for more details on model documentation.

In this section, salinity is analyzed as it relates to the salinity criteria set by the Colorado River Salinity Control Forum. For information on salinity concentration and salinity related to the potential effects on resources in the International Border Region, see **Appendix M**, International Border Region of the Colorado River.

Conditional box plots and vulnerability bar plots that describe impacts on water quality can be found in **TA 6**. Refer to **Section 3.2**, Analysis Methods, for additional information on interpreting the DMDU robustness heat maps and vulnerability bar plots.

Impact Analysis Area

The analysis area for water quality is the geographic and temporal scope introduced in **Section 3.2**, Analysis Methods. Due to the data available, the analysis was limited to surface water quality.

Assumptions

- There will be modifications in quantity, timing, temperature, and quality of water released from Glen Canyon Dam and Hoover Dam.

Impact Indicators

- Salinity
- Temperature
- Dissolved oxygen
- Reservoir elevation
- Dilution capacity

Issue 1: How would reservoir storage, reservoir releases, and corresponding changes in river flows downstream of the reservoirs affect salinity?

Increased salinity concentrations from human activities pose a threat to drinking water, irrigation, agricultural production, municipal water supplies, and infrastructure. Reservoirs like Lake Powell and Lake Mead influence salinity by attenuating salinity transport downstream and possibly acting as a source or a sink (Deemer 2020). Dam releases are typically from deeper in the water column and generally have elevated salinity concentrations relative to surface waters. As reservoir water levels drop, reservoir salinity can often increase (Zohary and Ostrovsky 2011).

Using CRSS outputs, annual flow-weighted average salinity concentrations below Hoover Dam, below Parker Dam, and at Imperial Dam were simulated under various hydrologic conditions. Under all alternatives, a majority (90 percent or greater) of simulated futures did not exceed the salinity criteria in even the most challenging hydrologic conditions.

For the Average Flow Category (12.0–14.0 maf), maximum simulated annual flow-weighted salinity concentrations exceeded the salinity threshold below Hoover Dam under the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives. See **Figure TA 6-4** in **TA 6**, Water Quality, for box plots depicting these annual flow-weighted average salinity concentrations.

Overall, simulated annual flow-weighted salinity concentrations were greatest under the Critically Dry Flow Category (4.46–10.0 maf) under all alternatives due to the low reservoir elevations associated with these hydrologic conditions. Simulated flow-weighted average salinity concentration median values did not exceed salinity thresholds at all sites under all alternatives, even under the driest flow scenarios.

Considering robustness, a majority of simulated futures under all alternatives did not exceed the salinity criteria established by the Colorado River Basin Salinity Control Forum below Hoover Dam, below Parker Dam, or at Imperial Dam. Compared with the other alternatives, the No Action Alternative exceeded the salinity threshold below Hoover Dam under the highest percentage of futures over the full modeling period. See **Figures TA 6-5**, **TA 6-6**, and **TA 6-7** in **TA 6**, Water Quality, for robustness plots of the percentage of futures in which the salinity concentration is less than salinity criteria below Hoover Dam, below Parker Dam, and at Imperial Dam in 100 percent of years.

In a vulnerability analysis of conditions that could cause salinity concentrations below Hoover Dam to exceed 723 mg/L, the hydrologic conditions associated with undesirable performance for the No Action Alternative (9.8 maf) are less than that of the median of previously observed hydrology in the reference ensemble. The hydrologic conditions associated with undesirable performance for the Basic Coordination, Enhanced Coordination, and Maximum Operational Flexibility Alternatives are less than the 25th percentile of previously observed hydrology in the reference ensemble. Further, the hydrologic conditions associated with undesirable performance for the Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) (6.8 maf) are less than that of any previously observed conditions in the reference hydrology (7.8 maf). See **Figure TA 6-8** in **TA 6**, Water Quality, for additional information on the vulnerability plot displaying conditions that could cause salinity below Hoover Dam to exceed 723 mg/L in one or more years under each alternative.

Issue 2: How would reservoir storage, reservoir releases, and the corresponding changes in river flows downstream of the reservoirs affect water temperature?

Water temperature strongly influences biological and chemical processes. For example, the temperature of dam releases affects fish population dynamics in downstream river segments, and elevated reservoir temperatures can lead to harmful algal blooms. **Sections TA 8.2.3**, Issue 2 and **TA 8.2.5**, Issue 4 in **TA 8**, Biological Resources – Fish and Other Aquatic Species, describe the impacts of temperature on fish and other aquatic species at temperature thresholds of 12 °C, 16 °C, and 20 °C (53.6 °F, 60.8 °F, and 68 °F).

Using outputs from GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry, and Grand Canyon, the annual average of daily temperatures and annual maximum Colorado River temperatures at Lees Ferry were simulated under various hydrologic conditions. As shown in **Figure TA 6-9** in **TA 6**, Water Quality, at Lees Ferry under the Wet and Moderately Wet Flow

Categories, all alternatives had similar simulated median temperatures. However, under the Average Flow Category, the Enhanced Coordination and Maximum Operational Flexibility Alternatives had lower median simulated annual average and maximum daily temperatures, with a narrower interquartile range, compared with the other alternatives at both Lees Ferry and Pearce Ferry. However, in the Average Flow Category, the simulated temperatures under the Enhanced Coordination and Maximum Operational Flexibility Alternatives had lower median values and a narrower interquartile range than the other alternatives.

Under the Dry and Critically Dry Flow Categories, simulated median values for temperatures increased across alternatives, compared with the Wet and Moderately Wet Flow Categories, and the Enhanced Coordination Alternative had the lowest median values for simulated average and maximum temperatures. Additionally, the interquartile ranges increased across all alternatives, indicating more variability in the annual average of daily temperatures and maximum temperatures as flow conditions become drier. The CCS Comparative Baseline had the highest maximum median temperature compared with all alternatives. For additional information on the simulated average and maximum Colorado River temperatures at Lees Ferry under various hydrologic conditions, see **TA 6**, Water Quality.

Considering the impacts on fish and other aquatic species, the Enhanced Coordination Alternative had the greatest number of simulated futures that maintained cooler water temperatures at Lees Ferry. These cooler temperatures are beneficial for rainbow trout, and they limit smallmouth bass reproduction, but these temperatures also inhibit native fish growth and reproduction. See **TA 8**, Biological Resources – Fish and Other Aquatic Species, for additional information on changes in water temperature from Glen Canyon Dam downstream through the Grand Canyon to Pearce Ferry and impacts on sportfish, native Grand Canyon fish, and nonnative predatory fish. See **TA 14**, Recreation, for more detailed information on temperature impacts associated with sportfish populations.

Issue 3: How would reservoir storage, reservoir releases, and the corresponding changes in river flows downstream of the reservoirs affect dissolved oxygen?

Dissolved oxygen dynamics can be affected by reservoir drawdowns through several pathways, including remobilization of deposited sediment as water levels change. As older reservoirs like Lake Powell experience lower elevations, there is greater metalimnion dissolved oxygen consumption, with larger spring snowmelt inflows furthering dissolved oxygen declines (Deemer et al. 2025). Dissolved oxygen is also affected by certain operations. For example, as reservoir levels decrease below 3,490 feet at Lake Powell, use of the river outlet works is triggered; this leads to high dissolved oxygen concentrations downstream of Glen Canyon Dam due to aeration as water passes through the river outlet works (Vernieu 2010).

Using outputs from GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry, and Grand Canyon, minimum annual dissolved oxygen concentrations released from Glen Canyon Dam under each alternative were simulated under various hydrologic conditions. Under drier conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives generally had higher simulated minimum annual dissolved oxygen concentrations than the other alternatives. See **Figure TA 6-10** in **TA 6**, Water Quality, for additional information on minimum annual dissolved oxygen concentration released from Glen Canyon Dam under various hydrologic conditions.

Below 3,490 feet at Lake Powell, releases from the river outlet works would effectively aerate the water, but its use would be limited over the long term to protect Glen Canyon Dam infrastructure. Therefore, elevation at Lake Powell below 3,490 feet and minimum annual dissolved oxygen concentration greater than 2 mg/L were considered. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are the only alternatives under which simulated minimum dissolved oxygen concentrations are greater than 2 mg/L in a majority of futures (greater than 50 percent) for the full modeling period. The simulated minimum dissolved oxygen concentrations are greater than 2 mg/L in the fewest number of futures under the CCS Comparative Baseline and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) across the full modeling period. See **Figure TA 6-13** in **TA 6**, Water Quality, for additional information on the robustness of minimum annual dissolved oxygen concentration where the Lake Powell elevation stays above 3,490 feet.

Due to the limitation of long-term use of the river outlet works, vulnerability was only analyzed for conditions that could cause dissolved oxygen concentration less than 2 mg/L or Lake Powell elevation below 3,490 feet in more than 10 percent of years. The Enhanced Coordination and Maximum Operational Flexibility Alternatives only resulted in undesirable performance (dissolved oxygen concentrations from Glen Canyon Dam releases falling below 2 mg/L or Lake Powell elevations below 3,490 feet) below the lowest 25 percent of observed hydrologic conditions. The hydrologic conditions associated with undesirable performance for the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives fall within a majority of hydrologic conditions that have already been observed. See **Figure TA 6-14** in **TA 6**, Water Quality, for additional information on the vulnerability analysis of conditions that could cause a dissolved oxygen concentration less than 2 mg/L or Lake Powell elevation below 3,490 feet in more than 10 percent of years.

Dissolved oxygen impacts on fish were also analyzed by considering dissolved oxygen concentrations less than 3 mg/L, which is a concentration that leads to reduced survival and feeding efficiencies. Under the Critically Dry Flow Category (4.46–10.0 maf), Lake Powell elevations stay above 3,490 feet, and the simulated minimum annual dissolved oxygen concentration is greater than 3 mg/L in at least 90 percent of the years in a majority of futures under the Enhanced Coordination Alternative; this occurs under the other alternatives in less than 50 percent of futures, which is critical for fish survival and feeding efficiencies. See **TA 8**, Biological Resources – Fish and Other Aquatic Species, for more information on the impact of dissolved oxygen on fish.

Issue 4: How would reservoir storage, reservoir releases, and the corresponding changes in river flows downstream of the reservoirs affect harmful algal blooms and nutrients?

Cyanobacteria blooms can alter physical and chemical water quality properties, threaten aquatic species, and release toxins into waterbodies, leading to health effects on recreationists and affecting water supplies. In a mixed-methods literature review assessing risk for cyanobacteria and phytoplankton in response to water level changes, with potential application to Lake Powell and Lake Mead, cyanobacteria were substantially more likely to increase in response to decreases in water levels. The review also suggested that the prevalence of cyanobacteria increases when reservoir water levels decline, subsequently increasing the risk of cyanobacterial blooms in reservoirs with more severe fluctuations in water levels (Hoffman 2025). However, examples also exist of no marked water quality response to long-term water level drawdown, including at Lake Mead. For example, Lake Mead experienced dramatic multiyear reductions in the water level with no apparent effects on nutrient or chlorophyll concentrations (Hannoun and Tietjen 2022).

In a qualitative analysis of simulated reservoir elevations at Lake Powell, the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives would pose an increased risk of cyanobacterial blooms due to the lower simulated Lake Powell elevations. These increased risks would be greatest under the Critically Dry Flow Category (4.46–10.0 maf) associated with lower reservoir elevations. The Enhanced Coordination Alternative had the greatest number of simulated futures in which the maximum annual change in water surface elevation was less than 30.71 feet in 5 years or more out of 10 years during the full modeling period. This could decrease the risk of cyanobacterial blooms associated with severe fluctuations in water levels under the Enhanced Coordination Alternative, compared with the other alternatives. For additional information about water quality impacts related to cyanobacteria, see **Section TA 6.2.5**, Issue 4, in **TA 6**, Water Quality. For additional information on how operational activities for the various alternatives would affect reservoir elevations, see **Section TA 3.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources.

Issue 5: How would reservoir storage and reservoir releases affect reservoir dilution capacity?

Generally, as reservoir elevations decrease, the dilution capacity of reservoirs like Lake Powell and Lake Mead also decrease. Decreased dilution capacity from lower reservoir elevations could result in greater concentrations of pollutants of concern, such as PFAS and perchlorate.

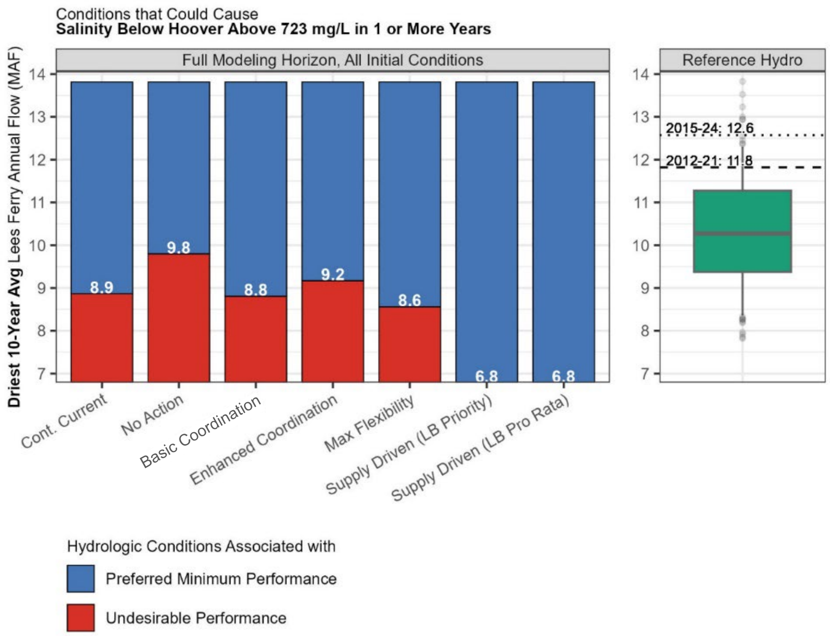
Given the current data and modeling capabilities, the impacts of the alternatives on pollutants of concern could not be quantitatively assessed. A qualitative review of reservoir elevations under **Section TA 3.2.1**, Issue 1: Reservoir Elevations, indicates that the impact of decreased dilution capacity associated with lower reservoir elevations on pollutants of concern, such as PFAS and perchlorate, would be greatest under the alternatives with the lowest median WY minimum reservoir elevations, including the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives. However, this impact would likely be negligible since it is unlikely that any of the reservoir elevations under the alternatives would significantly reduce dilution capacity or increase the concentration of pollutants of concern.

Summary Comparison of Alternatives

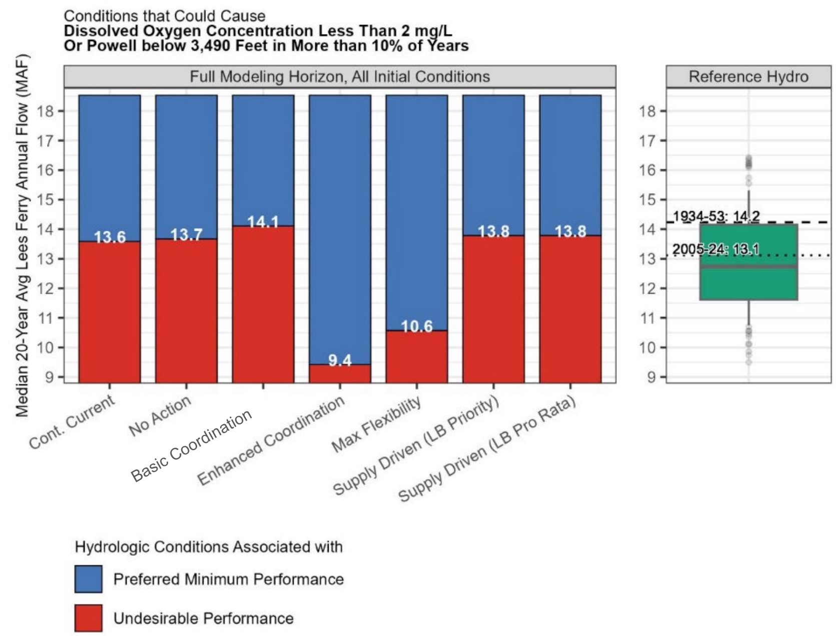
In a comparison of the vulnerability analyses for conditions that could cause undesirable performance for simulated salinity and dissolved oxygen, **Figure 3-17** shows that, generally, the CCS Comparative Baseline, No Action Alternative, and Basic Coordination Alternative are vulnerable to undesirable performance under a relatively wide range of conditions for both simulated salinity and dissolved oxygen compared to the least vulnerable alternatives. **Figure 3-17** also shows that there are vulnerability trade-offs between the two indicators associated with the other alternatives.

Figure 3-17
Conditions that Could Cause Undesirable Performance for Salinity and Dissolved Oxygen

Salinity*



Dissolved Oxygen**



*Undesirable performance for salinity means conditions that could cause salinity below Hoover Dam above 723 mg/L in one or more years.
**Undesirable performance for dissolved oxygen means conditions that could cause dissolved oxygen concentration less than 2 mg/L or Lake Powell elevation below 3,490 feet in more than 10 percent of years.

Considering simulated salinity, under the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches), the hydrologic conditions associated with undesirable performance (a 10-year drought averaging 6.8 maf or lower) are drier than any conditions in the observed record or the reference hydrology ensemble, in which the lowest 10-year drought averaged 7.8 maf, so they have low vulnerability. However, vulnerability with respect to dissolved oxygen is high: the median 20-year-average flows associated with undesirable performance under the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches) was 13.8 maf; this is close to the median 20-year average flow for the entire observed record, and wetter than the average flow from 2005 to 2024 (13.1 maf). Additionally, almost 75 percent of the traces in the reference hydrology ensemble have median 20-year average flows drier than this.

Similarly, there are vulnerability trade-offs associated with the Enhanced Coordination and Maximum Operational Flexibility Alternatives. Considering simulated dissolved oxygen, the Enhanced Coordination Alternative would be vulnerable if the median 20-year-average flow was 9.4 maf or drier, and the Maximum Operational Flexibility Alternative would be vulnerable in the median 20-year-average flow was 10.6 maf or drier; these conditions are drier than 90 to 100 percent of the traces in the refence hydrology ensemble and far below any observed 20-year-average flow. However, considering simulated salinity, the Enhanced Coordination and Maximum Operational Flexibility Alternatives result in undesirable performance under hydrologic conditions that are greater than the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches). Still, more than 75 percent of the traces in the reference hydrology ensemble are wetter than these values, so the vulnerability is not high.

In comparison of relative values for Lake Powell's reservoir elevation and the Colorado River temperature at Lees Ferry, the alternatives that had higher reservoir elevations, which decrease the risk for cyanobacterial blooms and increase the dilution capacity for pollutants, also had lower temperatures. This is because the Colorado River temperature at Lees Ferry is influenced in part by Lake Powell's reservoir elevation. The Enhanced Coordination Alternative had the highest median values for WY minimum Lake Powell elevations and the lowest average and maximum temperatures, compared with the other alternatives. The Maximum Operational Flexibility Alternative also had some of the highest median values for WY minimum Lake Powell elevations and some of the lowest average and maximum temperatures, compared with the other alternatives.

Overall, the Enhanced Coordination and Maximum Operational Flexibility Alternatives had the lowest vulnerability for dissolved oxygen and relatively better maximum and average Colorado River temperatures at Lees Ferry, compared with the other alternatives. These two alternatives were slightly more vulnerable with respect to simulated salinity compared with the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches); however, the hydrologic condition associated with undesirable salinity performance for the Enhanced Coordination and Maximum Operational Flexibility Alternatives were still drier than more than 75 percent of the traces in the reference hydrology ensemble.

3.7 Air Quality

3.7.1 Affected Environment

This section presents the existing conditions, regulatory framework, applicable laws, and available studies and resources related to air quality. Congress enacted the Clean Air Act (CAA) to ensure acceptable and nonhazardous air quality for the people of the U.S. The Environmental Protection Agency (EPA) subsequently established the National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment, referred to as criteria pollutants (EPA 2025a). **Table TA 7-1** shows the current NAAQS for each pollutant, which have been fully adopted by Utah, Arizona, and Nevada. The air pollutant sources in Arizona, Nevada, and Utah fall under different jurisdictions and each state implements regulations that further govern fugitive dust, which are discussed in more detail in **Section TA 7.1.4.**

For each criteria pollutant, the EPA classifies areas as in "attainment" if the area complies with the NAAQS or as "nonattainment" if one or more of the NAAQS are exceeded. Areas for which available data are not sufficient to make an attainment status designation are listed as unclassifiable. Air quality is considered in "attainment" or "unclassifiable" for all criteria pollutants within the Arizona counties of La Paz, Mohave, Coconino, Yavapai, and Navajo and the Utah counties of Washington, Kane, and San Juan. Clark County, Nevada, has been designated as serious nonattainment for the 2015 8-hour ozone (O_3) standard and a maintenance area for carbon monoxide (CO) and particulate matter less than 10 microns in diameter (PM_{10}); the county is considered in "attainment" or "unclassifiable" for all other pollutants (EPA 2025b). Air quality within Yuma County, Arizona, has been designated as marginal nonattainment for the 2015 8-hour O_3 standard and moderate nonattainment for PM_{10}; it is considered in "attainment" or "unclassifiable" for all other pollutants. Therefore, the General Conformity Rule would apply for O_3, CO, and PM_{10}. The general conformity de minimis thresholds for all pollutants are presented in **Table TA 7-2**.

CAA regulations also control the release of hazardous air pollutants (HAPs), which are chemicals that are known or suspected to cause cancer or other serious health effects. The NAAQS have not been set for HAPs; rather, HAP emissions are controlled by source type– or industrial sector–specific regulations using maximum achievable control technology standards. There are no project-specific applicable maximum achievable control technology requirements regarding HAPs, as these standards only apply to stationary sources within specific industrial groups.

Several tables present the existing conditions for the analysis area. Criteria pollutants are monitored throughout various parts of the country. The EPA uses the criteria pollutant monitoring data to determine a "design value" for each pollutant and averaging time, which can be compared with the NAAQS. The most recent available 2024 design values for the analysis area counties are provided in **Table TA 7-5**, **Table TA 7-3**, and **Table TA 7-4**. The design value for O_3 for Clark County exceeds the NAAQS for O_3 (0.70 parts per million), and the number of exceedances of the PM_{10} NAAQS exceeds the standard for Clark County. No other design value listed in **Table TA 7-5**, **Table TA 7-3**, and **Table TA 7-4** exceed or approach proximity to the NAAQS (EPA 2025c). In addition, triennially, the EPA publishes a comprehensive summary of air emissions data, known as the National Emissions Inventory (NEI). **Table TA 7-7** through **Table TA 7-9** present the most recent 2020 emissions for the six criteria air pollutants and HAPs for the U.S.; the states of Arizona, Nevada, and Utah; and all counties in the analysis area. The EPA uses the NEI to develop and review regulations, conduct air quality modeling, and conduct risk assessments to understand how air pollution may affect the health in communities across the country.

As set forth in the CAA, the EPA developed and implemented the Prevention of Significant Deterioration (PSD) regulations to protect public health and welfare and to preserve, protect, and enhance the air quality in areas of special value. As part of the PSD, the EPA classifies airsheds as Class I, which are areas for which the PSD regulations provide special protection, or Class II, which allows for moderate pollution increases and reasonable growth, while still applying stringent air quality constraints (NPS 2023a). **Table TA 7-10** presents the Class I areas located within the analysis area and those located in counties adjacent to the analysis area. For those Class I areas that are national parks, the table also provides visibility data. **Table TA 7-10** shows that the visibility ranges from fair to good. In addition, the NPS monitors and evaluates deposition to identify parks that are most at risk and where conditions are declining or improving (NPS 2024a). **Table TA 7-11** shows that nitrogen deposition conditions are fair to poor and sulfur deposition conditions are good, with trend data unavailable for most locations.

Regional modeling, studies, and data discussed that pertain to the analysis area are as follows:

- Lake Powell and Lake Mead Modeling: This is a 2024 study to model the exposed shoreline area and potential dust emissions at the two reservoirs (Sankey et al. 2024).
- Lake Mead Annual High and Low Elevations: Annual high and low elevations of Lake Mead for years 1935–2024 are available from Reclamation.
- Lake Powell Annual High and Low Elevations: Annual high and low elevations of Lake Powell for years 1964–2024 are available from Reclamation.
- Lake Mead Mapping: The USGS completed a detailed geophysical mapping of the floor of Lake Mead during 1999, 2000, and 2001. These data indicate that a large volume of sediment carried by the Colorado River has accumulated in Lake Mead.
- Lake Powell Mapping: This is a survey of Lake Powell for the purpose of calculating the elevation-area-capacity relationships in Lake Powell.
- Impact of Lost Generation at the Glen Canyon Powerplant: This report presents data showing the changes in generation sources for each of the years 2024–2027.
- Research on Emission from U.S. Reservoirs: EPA scientists are collaborating with researchers at the U.S. USGS and U.S. Department of Energy to measure methane and carbon dioxide (CO_2) emissions from 108 U.S. reservoirs during a 4-year survey that took place from 2020 through 2023.

Climate trends and CO_2, methane, nitrous oxide, and carbon dioxide equivalent (CO_2e) emissions are also discussed. Climate trends result from several factors, including the release of pollutants, land use management practices, and the albedo effect, which is the reflectivity of various surfaces, including the reflectivity of clouds. Effects from these pollutants are mostly indirect in that they do not necessarily have a negative impact on human health near emission sources or at the time of release. Rather, they accumulate in the atmosphere and affect weather and climate on a global scale over time. Estimates of CO_2, methane, and nitrous oxide emissions are usually reported in terms of CO_2e to account for the relative conversion factor, which was developed to allow comparison of global impacts between different gases.

Several tables present the existing conditions for the analysis area. **Table TA 7-12** lists the industry sector and total CO_2e emissions for the most recent reporting years for the U.S. (EPA 2024) and for Nevada from the Nevada Division of Environmental Protection Air Program (NDEP 2024). Arizona does not maintain a statewide emissions inventory. **Table TA 7-13** through **Table TA 7-16** provide the 2020 NEI CO_2, methane, nitrous oxide, and CO_2e emissions for the U.S., Nevada, and Arizona. In addition, NEI data are provided for each county in the analysis area (EPA 2023).

Past and present climate trends and impacts are also provided for Nevada, Arizona, and Utah. An analysis of regional climate impacts concluded that the rate of average annual temperature increases in the southwest U.S. was among the most rapid nationally (IPCC 2021). Analysis of past records indicates an overall increase in regional temperatures, including in the analysis area. The National Oceanic and Atmospheric Administration's National Centers for Environmental Information released its climate summaries by state in 2022. The climate summaries for the analysis area states are summarized. More detailed climate discussions for each state can be found through the State Climate Summaries web page (NOAA 2022).

Section TA 7.1.6 provides climate trends and CO_2e regulatory framework information, including applicable laws, regulations, plans, and policies. Through statutes, executive orders, and agency policies, the federal government seeks to ensure a reliable, affordable, and secure energy supply while supporting efficient use of resources and responsible development of energy infrastructure. Federal actions may also consider potential energy use and emissions effects, as appropriate, in order to inform decision-making and evaluate alternatives consistent with applicable laws and regulations.

3.7.2 Environmental Consequences

Methodology

This section examines potential effects on air quality resources under the action alternatives and the No Action Alternative, compared with the CCS Comparative Baseline. Potential impacts are considered for the following air quality resources: shoreline exposure area, fugitive dust emissions, changes in CO_2e due to hydropower, and climate trends.

The CRSS model is used in the hydrologic analysis, and the output is organized into five flow condition categories. The five flow condition categories are framed as the Wet Flow Category (16.0–31.11 maf), Moderately Wet Flow Category (14.0–16.0 maf), Average Flow Category (12.0–14.0 maf), Dry Flow Category (10.0–12.0 maf), and Critically Dry Flow Category (4.46–10.0 maf). There are 400 different hydrologic traces for each year over a 34-year period, as shown in **Figure TA 7-2** in **TA 7**, Air Quality.

The shoreline exposure analysis used previously published topographic and bathymetric surveys and geologic mapping (Hirschberg and Pitts 2000; Jones and Root 2021, 2022; Ferrari 2001; Root et al. 2019; Root and Jones 2022; Twichell et al. 2003; Twichell and Cross 2009; Wilson et al. 1969) with new predictions of potential dust emissions using the FENGSHA model (Mallia et al. 2017). The results are presented as Glen Canyon and Lake Mead exposed shoreline area and associated emission rates (Fischella et al. 2026). Impacts on shoreline exposure and fugitive dust emissions are then described using conditional box plots, as well as DMDU robustness heat maps and vulnerability bar plots. In a conditional box plot, the bold center line of each box represents the median value, the top and bottom of each box capture the 25th to 75th percentile of the modeled results, the lines extend to the 10th and 90th percentiles, and the outliers are represented as dots beyond these lines. Refer to **Appendix E**, DMDU Overview and Approach, for an overview of how to interpret the DMDU robustness heat maps and vulnerability bar plots.

The increase or decrease in metric tons of CO_2e emissions due to changes in hydropower generation at Glen Canyon Dam, Hoover Dam, Parker Dam, and Davis Dam are presented in conditional box plots. The conditional box plot for each dam compares median CCS Comparative Baseline generation to median generation for each alternative and multiple natural flow groups. In each year of every modeled future, the difference in annual hydropower generation between the CCS Comparative Baseline and each alternative was computed to determine the change in generation, whether that be an increase or a decrease. The annual change in generation was multiplied by the 2025 and 2050 Emissions and Generation Resource Integrated Database/National Laboratory of the Rockies emission factor. **Table TA 7-19** and **Table TA 7-20** in **TA 7**, Air Quality, show how the 2025 and 2050 weighted average emission factors were calculated. These emission factors represent the potential CO_2e from each resource type per megawatt-hour (MWh) and the current and future resource mix percentages for the Western Regional Climate Center energy production. The weighted emission factors are multiplied by the changes in MWh for each alternative and flow category.

Impact Analysis Area

The geographic scope of the air quality resources analysis includes Lake Powell to the SIB, which includes Mohave, Coconino, Yavapai, and Navajo Counties in Arizona; Washington, San Juan, and Kane Counties in Utah; and Clark County, Nevada. Specifically, the shoreline exposure analysis area includes Lake Mead and Lake Powell. The analysis areas for changes in CO_2e due to hydropower generation include Glen Canyon Dam, Hoover Dam, Parker Dam, and Davis Dam. The climate trends analysis area is discussed for the western U.S.

Assumptions

- The hydrologic resources results are direct results from the CRSS model. Refer to **Appendix A**, CRSS Model Documentation, for more details related to model assumptions and documentation.
- The National Laboratory of the Rockies publishes life cycle assessments and which CO_2e emission factors are associated with each type of electricity generation (NLR 2021).
- The EPA 2023 Emissions and Generation Resource Integrated Database was used to determine the North American Electric Reliability Corporation resource mix (coal, natural gas, oil, nuclear, hydropower, biomass, wind, solar, and geothermal sources) for the Western Electricity Coordinating Council region (EPA 2025d).

- The U.S. Energy Information Administration's Annual Energy Outlook 2023 (EIA 2023) provides the potential generation mix for 2050.
- The equivalency calculator is used to convert emissions into concrete, understandable terms, such as the annual CO_2 emissions of cars, households, and power plants (EPA 2025e).

Impact Indicators

Specific impact indicators were selected to help frame the air quality resources analysis for each alternative. The following indicators were used to assess impacts:

- Shoreline Exposure: These are effects on the shoreline exposure area due to operational activities.
- Shoreline Dust Emissions: These are effects on shoreline dust emissions due to operational activities.
- Change of CO_2e Emissions due to a Loss of Hydropower Generation: These are effects on CO_2e emissions due to operational activities.

Issue 1: How would changing flow characteristics affect the potential exposed shoreline, fallowed agricultural lands, and fugitive dust?

Changes in water storage in lakes can affect the area of shoreline sediment exposed subaerially and potentially available for aeolian transport. This resource modeling evaluates how potential changes in reservoir water storage might affect potential dust emissions from subaerially exposed reservoir sediment. Relationships between potential dust emissions and water storage could be useful for evaluating air quality and related resource impacts associated with Colorado River water management decisions.

Figure TA 7-3 in **TA 7**, Air Quality, shows the WY maximum exposed shoreline area for Lake Powell and Lake Mead. In the Average Flow Category (12.0–14.0 maf), the medians and interquartile ranges for all alternatives for Lake Powell are projected to remain above 200 square kilometers (km^2) of maximum shoreline exposure. The CCS Comparative Baseline and the No Action Alternative have higher variable results, centered around 400 km^2 of maximum shoreline exposure, while the Supply Driven and Basic Coordination Alternatives have less variance but are still centered around 400 km^2 of maximum shoreline exposure. In the Average Flow Category (12.0–14.0 maf), the medians and interquartile ranges for all alternatives for Lake Mead are projected to remain above 125 km^2 of maximum shoreline exposure. The CCS Comparative Baseline and the No Action Alternative have lower variable results, but the median for both alternatives is higher than it is under all other alternatives. The Maximum Flexibility and Supply Driven Alternatives have lower medians than the other alternatives but also have the highest variability.

As flow categories get drier for WY minimums, the medians for all Lake Powell alternatives are above 400 km^2 of maximum shoreline exposure, and the medians have lower variability. As flow categories get drier for WY minimums, the medians for all Lake Mead alternatives are above 300 km^2 of maximum shoreline exposure, with higher variability in the Basic Coordination and Supply Driven Alternatives. The Lake Powell alternatives generally perform similarly under wet hydrologic flow conditions. The CCS Comparative Baseline, the Basic Coordination Alternative, and the No Action Alternative have a higher km^2 of maximum shoreline exposure and higher variability, while the Maximum Flexibility, Supply Driven, and Enhanced Coordination Alternatives generally perform similarly with very low shoreline exposure and low variability.

Lake Mead Robustness

Figure TA 7-4 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping the Lake Mead shoreline exposure area below 500 km^2. The shoreline exposure area below 500 km^2 is important because it is an indicator for potential fugitive dust. The figure is broken into four heat maps, each showing a different time period during the analysis. The rows of the heat map show different frequency ranges (shoreline area) for keeping Lake Powell below this area; higher rows are associated with lower shoreline exposure. The color of a heat map's square corresponds with the percentage of futures that meet this level of performance. The percentage increases from a red color, which represents less than 10 percent of futures keeping the Lake Mead shoreline exposure area below the specified value on the left axis in every month (least robust), to a dark-blue color representing greater than 91 percent of futures keeping the Lake Mead shoreline exposure area below the specified value on the left axis in every month (most robust). The higher the percentage, the more likely Lake Mead shoreline exposure will remain below the specified km^2 under most future hydrologic scenarios.

Figure TA 7-4 in **TA 7**, Air Quality, shows that the Maximum Flexibility and Enhanced Coordination Alternatives are the most robust at staying below 500 km^2 of shoreline exposure in 90 percent of months over the full modeling period (shown in the top row), doing so in 89 percent and 84 percent of the futures, respectively. The No Action Alternative has the worst performance at a 40 percent success rate over the full analysis period. For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently achieve 81–100 percent robustness (the two darkest blues), while the No Action Alternative only reaches a maximum of 64 percent robustness at even the lowest levels of performance for the 500 km^2 of shoreline exposure category.

Figure TA 7-5 in **TA 7**, Air Quality, shows flow conditions that could cause the Lake Mead shoreline exposure area to be above 500 km^2 in one or more months. This definition of undesirable performance is based on the highlighted row in **Figure TA 7-4**, which qualifies a future as successful in meeting the preferred minimum performance when an alternative would kept Lake Mead below this critical buffer shoreline exposure area of 500 km^2 for 100 percent of the time. For the vulnerability analyses, the driest 20-year average of Lees Ferry annual flow during the full modeling period was used as the reference hydrology. The reference hydrology shows the distribution of the driest 20-year averages included in the reference ensemble, with the median 20-year average for Lees Ferry flow being around 11.6 maf. The reference hydrology box plot also includes the driest observed 20-year average flow from 2002 to 2021 (12.5 maf) and the most recent observed 20-year average from 2005 to 2024 (13.1 maf) as dashed lines, for comparison.

The Enhanced Coordination, Maximum Flexibility, and Supply Driven Alternatives are vulnerable to similar conditions: 20-year droughts of 9.5 maf, 8.1 maf, and 10.1 maf, respectively. The No Action Alternative is the most vulnerable; Lake Mead is likely to go below 1,000 feet elevation in a 20-year drought averaging 12.2 maf. From 2002 to 2021, the 20-year average was 12.4 maf, so the No Action Alternative is just below the vulnerability of conditions that have already occurred.

Lake Powell Robustness

Figure TA 7-6 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping the Lake Powell shoreline exposure area below 500 km^2. The Maximum Flexibility and Enhanced Coordination Alternatives are the most robust at staying below 500 km^2 of shoreline exposure in 85 percent of months over the full modeling period (shown in the bottom row), doing so in 95 percent and 86 percent of the futures, respectively. The No Action Alternative has the worst performance at a 24 percent success rate over the full analysis period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently achieve 86–100 percent robustness (the two darkest blues), while the No Action Alternative only reaches a maximum of 51 percent robustness at even the lowest levels of performance for the 500 km^2 of shoreline exposure category.

Figure TA 7-7 in **TA 7**, Air Quality, looks at flow conditions that could cause the Lake Powell shoreline exposure area to be above 500 km^2 in one or more months. For this vulnerability analysis, the driest 10-year average of Lees Ferry annual flow during the full modeling period was used as the reference hydrology and is shown in the box plot to the right of the vulnerability bar plot. This drought reference hydrology shows the distribution of the driest 10-year averages in the reference ensemble with a median 10-year-average Lees Ferry flow of around 10.3 maf. The reference hydrology box plot also includes the averages for 2012–2021 (11.8 maf) and 2015–2024 (12.6 maf) as dashed lines, for comparison.

The Enhanced Coordination and Maximum Operational Flexibility Alternatives are vulnerable to similar conditions: 10-year droughts of 9.2 maf and 8.0 maf, respectively. The CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven Alternatives have 10-year droughts of 12.3, 12.9, 12.7, and 12.0, respectively, which are all above the reference hydrology box plot averages for 2012–2021 (11.8 maf) and 2015–2024 (12.6 maf). Therefore, these alternatives are all more vulnerable and likely to cause undesirable performance.

Shoreline Exposure

Figure TA 7-8 in **TA 7**, Air Quality, shows the WY maximum shoreline dust emissions for Lake Powell and Lake Mead. In the Average Flow Category (12.0–14.0 maf), the medians and interquartile ranges for all alternatives for Lake Powell are projected to remain above 100 million kilograms (kg) of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) as a result of shoreline exposure. The CCS Comparative Baseline and the Supply Driven, Basic Coordination, and No Action Alternatives all have similar medians and higher variabilities. The Enhanced Coordination and Maximum Operational Flexibility Alternatives have lower medians and small variabilities. Therefore, these two alternatives would result in less $PM_{2.5}$ than the other four alternatives.

For Lake Mead, the medians and interquartile ranges for all alternatives are projected to remain above 70 million kg of $PM_{2.5}$ as a result of shoreline exposure. The Lake Mead No Action Alternative has the highest median and 75th percentile; therefore, it is the alternative with the largest amount of $PM_{2.5}$ as a result of shoreline exposure. The Supply Driven and Maximum Operational Flexibility Alternatives have the lowest medians and higher variability. As flow categories get drier for WY minimums, the medians for all Lake Powell and Lake Mead alternatives increase the millions of kg of $PM_{2.5}$. As flow categories get wetter for WY minimums, the potential $PM_{2.5}$ decreases.

Lake Mead Robustness

Figure TA 7-9 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping Lake Mead $PM_{2.5}$ below 600 kg from a shoreline exposure area. The color of a heat map's square corresponds with the percentage of futures that meet this level of performance; the percentage increases from a red color representing less than 10 percent of futures keeping the Lake Mead emissions below 100 kg (least robust) to a dark-blue color representing greater than 91 percent of futures keeping the Lake Mead emissions above 500 kg (most robust). The higher the percentage, the more likely Lake Mead will remain above the minimum power pool (950 feet) under most future hydrologic scenarios. Keeping the Lake Mead emissions below 500 kg ensures that fugitive dust would be minimized, which would protect air quality in the area.

The Maximum Flexibility, Supply Driven, and Enhanced Coordination Alternatives are the most robust at staying below 500 kg in 80 percent of months over the full modeling period, doing so in 82 percent and 78 percent of the futures, respectively. The Basic Coordination Alternative performs similarly to the CCS Comparative Baseline, if not slightly better, succeeding in 59 percent of futures over the full analysis period. The No Action Alternative has the worst performance at a 27 percent success rate over the full analysis period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Enhanced Coordination, Supply Driven, and Maximum Operational Flexibility Alternatives consistently achieve 71–100 percent robustness (the three darkest blues in color), while the other alternatives only reach a maximum of 77 percent robustness at even the lowest levels of performance (for example, greater than or equal to 60 percent of months).

Figure TA 7-10 in **TA 7**, Air Quality, looks at flow conditions that could cause Lake Mead emissions above 500 million kg during at least one or more months. The Enhanced Coordination, Maximum Flexibility, and Supply Driven Alternatives are vulnerable to similar conditions: 20-year droughts of 10.2 maf, 9.9 maf, and 10.7 maf, respectively. The CCS Continued Baseline is more vulnerable, with a 20-year drought of 11.9 maf likely to cause undesirable performance. The No Action Alternative is the most vulnerable; Lake Mead would likely go below 1,000 feet elevation in a 20-year drought averaging 12.7 maf. From 2002 to 2021, the 20-year average was 12.4 maf; therefore, the No Action Alternative is just above the vulnerability of conditions that have already occurred.

Lake Powell Robustness

Figure TA 7-11 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping Lake Powell $PM_{2.5}$ from a shoreline exposure area below 650 kg. The color of a heat map's square corresponds with the percentage of futures that meet this level of performance; the percentage increases from a red color, which represents less than 10 percent of futures keeping the Lake Powell emissions below 150 kg (least robust), to a dark-blue color, which represents greater than 91 percent of futures keeping the Lake Powell emissions above 450 kg (most robust). Keeping the Lake Powell emissions below 450 kg ensures that fugitive dust would be minimized, which would protect air quality in the area.

The Maximum Flexibility and Enhanced Coordination Alternatives are the most robust at staying above elevation 3,500 feet in 100 percent of months over the full modeling period (shown in the top row), doing so in 87 percent and 82 percent of the futures, respectively. The Basic Coordination, Supply Driven (LB Priority approach), and Supply Driven (LB Pro Rata approach) Alternatives perform similarly to the CCS Comparative Baseline, if not slightly worse, succeeding in 25 percent, 24 percent, and 24 percent of futures, respectively, over the full analysis period. The No Action Alternative has the worst performance at a 20 percent success rate over the full analysis period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently achieve 91–100 percent robustness (dark blue in color), while the other alternatives only reach a maximum of 80 percent robustness at even the lowest levels of performance (for example, greater than or equal to 60 percent of months).

Figure TA 7-12 in **TA 7**, Air Quality, looks at flow conditions that could cause the Lake Powell elevation to fall below 3,500 feet during at least 1 month in any year. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are vulnerable to similar conditions: 10-year droughts of 9.4 and 8.0 maf, respectively. These conditions are near the 10th percentile of the reference hydrology ensemble, so only about 10 percent of the traces include droughts this dry or drier. The CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven Alternatives have 10-year droughts of 12.5, 13.1, 12.9, and 12.7, respectively, which are all above the reference hydrology box plot averages for 2012–2021 (11.8 maf) and 2015–2024 (12.6 maf). Therefore, these alternatives are all more vulnerable and likely to cause undesirable performance.

Other effects are the potential dust-on-snow effects, which may occur when reservoir elevations are low, and there are more dust mobilization and potential acceleration of runoff. Also, changing flow characteristics can affect the fallowing of agricultural lands, especially in regions that rely on consistent irrigation from reservoirs.

Clark County, Nevada, is the only county in the analysis area that has been designated as serious nonattainment for the 2015 8-hour O_3 standard and a maintenance area for CO and PM_{10} (EPA 2025b). The potential shoreline exposure discussed above has the potential to increase particulate matter that could further exacerbate the current PM_{10} issue in Clark County.

Issue 2: How would lake reservoir elevations and releases impact power generation and CO_2e emissions?

Issue 2 addresses how operational activities for the various alternatives affect reservoir elevations and, therefore, impact hydropower generation. When there is a reduction of hydropower, there would be a potential increase of CO_2e emissions because more emissive alternative energy generation would compensate for this reduction. The box plots report metric tons of CO_2e based on the 2025 resource mix emission factor on the left axis and the 2050 resource mix emission factor on the right axis, using the MWh increase or decrease for each alternative and flow category. Only the

2025 resource mix is discussed in detail. This is because the 2050 resource mix results would have lower metric tons of CO_2e because the emission factor includes more alternative energy resources.

Figure TA 7-13 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a loss of hydropower at Glen Canyon Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), the alternatives are projected to result in a range of medians and variability of metric tons of CO_2e. The Supply Driven (LB Priority approach) and Supply Driven (LB Pro Rata approach) Alternatives have medians with a positive value of metric tons of CO_2e and similar variability. The positive CO_2e value indicates an increase in CO_2e compared with the CCS Comparative Baseline. The No Action and Basic Coordination Alternatives have medians resulting in a small metric ton decrease in CO_2e and a smaller interquartile range, indicating less variability. The Enhanced Coordination and Maximum Operational Flexibility Alternatives both result in a decrease in CO_2e. The Enhanced Coordination Alternative's variability ranges from a 251.8-metric-ton decrease in CO_2e at the 25th percentile to an 88.2-metric-ton increase in CO_2e.

In the Critically Dry Flow Category (less than 10.0 maf), all the alternatives, except the Enhanced Coordination and Maximum Operational Flexibility Alternatives, are projected to result in similar behavior, in terms of medians and variability, since they all show a potential increase of CO_2e compared with the CCS Comparative Baseline. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 100-metric-ton increase in CO_2e for the Supply Driven (LB Pro Rata approach) and Supply Driven (LB Priority approach) Alternatives, which is equivalent to 23.3 gasoline-powered passenger vehicles driven for 1 year or 20.8 homes' electricity for 1 year.

Figure TA 7-14 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a loss of hydropower at Hoover Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), the No Action Alternative has the highest median with a 156.8-metric-ton increase in CO_2e. All other alternatives have medians below zero (which is the CCS Comparative Baseline); therefore, they result in a decrease in CO_2e. The Supply Driven (LB Pro Rata approach) and the Supply Driven (LB Priority approach) Alternatives are the only alternatives with medians and the 25th and 75th percentile variability, resulting in a decrease in CO_2e.

In the Critically Dry Flow Category (less than 10.0 maf), the No Action Alternative's median is zero; it is the only alternative with the 25th to 75th percentile variability resulting in an increase in CO2e. The Basic Coordination Alternative's 75th percentile variable is zero, with the median and 25th percentile variable resulting in a decrease in CO_2e. The Supply Driven (both LB Priority and LB Pro Rata approaches) and Maximum Operational Flexibility Alternatives all have 75th percentile variables at zero. The No Action Alternative is the most reliable because it stays equal to or above the CCS Comparative Baseline under each flow category; therefore, it performs consistently the worst. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 387-metric-ton increase in CO_2e (under the No Action Alternative), which is equivalent to 90.3 gasoline-powered passenger vehicles driven for 1 year or 80.6 homes' electricity for 1 year.

Figure TA 7-15 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a loss of hydropower at Davis Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), the alternatives are projected to result in similar medians and variability of metric tons of CO_2e. The No Action Alternative is the only alternative with a median and 25th percentile below zero, resulting in a slight decrease in CO_2e. All other alternatives have medians and 25th to 75th percentiles that result in an increase in CO_2e. In the Critically Dry Flow Category (less than 10.0 maf), the Enhanced Coordination and Maximum Operational Flexibility Alternatives both have medians above that of the CCS Comparative Baseline (around 20 metric tons of CO_2e). The No Action, Basic Coordination, and Supply Driven (LB Priority approach) Alternatives all have medians just below zero.

The Maximum Flexibility and Enhanced Coordination Alternatives are the most reliable; this is because they stay equal to or above the CCS Comparative Baseline under each flow category, except the High Flow Category (16.0–31.0 maf). Therefore, they perform consistently the worst. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 43-metric-ton increase in CO_2e (under the Enhanced Coordination Alternative), which is equivalent to 10 gasoline-powered passenger vehicles driven for 1 year or 9 homes' electricity for 1 year.

Figure TA 7-16 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a loss of hydropower at Parker Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), the alternatives are projected to result in similar medians and variability of metric tons of CO_2e. However, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives have the highest medians and larger interquartile ranges, all resulting in a small increase in metric tons of CO_2e. Only the No Action and Basic Coordination Alternatives have medians that result in a decrease in CO_2e; however, the 25th percentiles are under a 3-metric-ton decrease of CO_2e.

In the Critically Dry Flow Category (less than 10.0 maf), the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives have the highest medians and larger interquartile ranges. The Enhanced Coordination Alternative is the only alternative with a median and a 75th and 25th percentile variance, resulting in a small increase in metric tons of CO_2e. The No Action and Basic Coordination Alternatives have medians just below zero, which is similar to the Maximum Flexibility and Supply Driven (LB Priority approach) Alternatives, and very small interquartile ranges. The Enhanced Coordination Alternative is the most reliable because it stays equal to or above the CCS Comparative Baseline under each flow category; therefore, it performs consistently the worst. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 23-metric-ton increase in CO_2e (under the Enhanced Coordination Alternative), which is equivalent to 5.4 gasoline-powered passenger vehicles driven for 1 year or 4.8 homes' electricity for 1 year.

Issue 3: How would climate trends affect lake reservoir elevations?

Climate trends affect lake reservoir elevations in several interrelated ways, driven largely by changes in temperature, precipitation patterns, and hydrologic cycles. Climate trends typically cause more variability and extremes in lake reservoir elevations, including lower lows during droughts, higher highs during storm events, and greater management complexity overall. The following are potential events that could be affected by climate trends and that would potentially affect reservoir elevations:

- Reduced snowpack and earlier snowmelt
- Increased evaporation rates from both lake surfaces and the surrounding land
- Changes in precipitation patterns
- Increased water demand

As discussed in Issue 2, climate events may affect hydropower. Any reduction in hydropower would require other power-generation sources to increase to compensate. The regional power mix can be analyzed to determine the region's potential capacity in order to replace hydropower with other alternative energy sources. Using available information from the eGRID for the analysis area, **Table TA 7-21** in **TA 7**, Air Quality, shows that renewables, such as hydropower, biomass, wind, solar, and geothermal sources, are 42.8 percent of the Western Electricity Coordinating Council's resource mix, compared with nonrenewable sources, such as coal, oil, nuclear, and gas, totaling 57.3 percent. If the 19.8 percent hydropower is reduced, it is likely that both renewable and nonrenewable resources would compensate.

However, a recent Argonne study shows that when there is a reduction in hydropower at Glen Canyon Powerplant, the replacement generation is from mostly natural gas–fired generation (gas-combined cycle) and generation from gas combustion turbines, with a small portion also coming from coal-fired generation for 2024 through 2027 (Argonne et al. 2024). In addition, as climate trends are further observed and monitored, Reclamation has an opportunity to discuss any strategies to increase management flexibility, enhance climate adaptation planning, and improve infrastructure resilience.

Summary Comparison of Alternatives

For the Lake Powell WY maximum exposed shoreline area with the Average Flow Category (12.0–14.0 maf), the alternatives all have similar medians and small variabilities, except the Enhanced Coordination and Maximum Operational Flexibility Alternatives, which have the lowest median km^2 of exposed shoreline and the smallest variability.

For the Lake Mead WY maximum exposed shoreline area with the Average Flow Category (12.0–14.0 maf), the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives performed the best, with the least shoreline exposure area. The CCS Comparative Baseline and the No Action Alternative perform the worst and have the smallest variability. The Basic Coordination Alternative performs in the middle.

For the full modeling period, the Lake Mead shoreline area robustness figures show that the No Action Alternative performs the worst, with only 40 percent of the futures below 500 km^2 of shoreline area. The CCS Comparative Baseline performs slightly better at 54 percent, then the Basic Coordination Alternative at 67 percent, and then the Supply Driven Alternative at 79 percent. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with over 80 percent of the futures below 500 km^2 of shoreline area. These same trends were seen for the 2027–2039, 2040–2049, and 2050–2060 modeling periods with higher percentages. For the 2027–

2039 modeling period and 2040–2049 modeling period, the Maximum Operational Flexibility and Enhanced Coordination Alternatives have over 90 percent of the futures below 500 km^2 of shoreline area.

The Lake Mead vulnerability plots show that the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives are vulnerable to similar conditions, and only about 10 percent of the traces include droughts this dry or drier. The Basic Coordination Alternative is just below the median 20-year average for the Lees Ferry flow. The CCS Comparative Baseline and the No Action Alternative are the most vulnerable, with a 20-year drought of 11.7 maf and 12.2 maf, respectively, likely to cause undesirable performance.

For the full modeling period, the Lake Powell shoreline area robustness figures show that the No Action Alternative performs the worst, with only 24 percent of the futures below 500 km^2 of shoreline area. The Supply Driven Alternative performs slightly better at 28 percent, then the Basic Coordination Alternative at 33 percent, and then the CCS Comparative Baseline at 40 percent. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with over 80 percent of the futures below 500 km^2 of shoreline area. These same trends were seen for the 2027–2039 period with higher percentages. The 2040–2049 and 2050–2060 modeling periods show that the Supply Driven Alternative performs the worst, followed by the No Action Alternative. For the 2027–2039, 2040–2049, and 2050–2060 modeling periods, the Maximum Operational Flexibility and Enhanced Coordination Alternatives have over 90 percent of the futures below 500 km^2 of shoreline area.

The Lake Powell vulnerability plots show that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are vulnerable to similar conditions, and only about 10 percent of the traces include droughts this dry or drier; therefore, these are the least vulnerable. The CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven Alternatives are above the median 10-year-average Lees Ferry flow and are the most vulnerable to a 10-year drought.

For the Lake Powell WY maximum shoreline dust emissions with the Average Flow Category (12.0–14.0 maf), the alternatives all have similar medians, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives having the lowest median km^2 of exposed shoreline and the smallest variability.

For the Lake Mead WY maximum shoreline dust emissions with the Average Flow Category (12.0–14.0 maf), the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives performed the best, with the least shoreline dust emissions. The CCS Comparative Baseline and the No Action Alternative perform the worst, with the highest shoreline dust emissions. The Basic Coordination Alternative performs in the middle.

For the full modeling period, the Lake Mead shoreline dust emissions robustness figures show that the No Action Alternative performs the worst, with only 27 percent of the futures below 500 million kg of $PM_{2.5}$. The CCS Comparative Baseline performs slightly better at 47 percent, then the Basic Coordination Alternative at 59 percent, and then the Supply Driven Alternative at 74 percent. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with over 82 percent and 78 percent, respectively, of the futures below 500 million kg of $PM_{2.5}$. These same trends were seen for the 2027–2039, 2040–2049, and 2050–2060 modeling periods with higher percentages. The Maximum Operational Flexibility and Enhanced Coordination Alternatives have over 80 percent of the futures below 500 million kg of $PM_{2.5}$.

The Lake Mead vulnerability plots show that the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives are vulnerable to similar conditions, and only about 10 percent of the traces include droughts this dry or drier; therefore, these alternatives are the least vulnerable. The CCS Comparative Baseline and the Basic Coordination and No Action Alternatives are the most vulnerable, with a 20-year drought of 11.9 maf, 11.4 maf, and 12.7 maf, respectively; these are over the 20-year average for the Lees Ferry flow of 11.6 maf and likely to cause undesirable performance.

For the full modeling period, the Lake Powell shoreline dust emissions robustness figures show that the No Action Alternative performs the worst, with only 22 percent of the futures below 450 million kg of $PM_{2.5}$. The Supply Driven Alternative performs slightly better at 27 percent, then the Basic Coordination at 29 percent, and then the CCS Comparative Baseline at 35 percent. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best, with over 80 percent of the futures below 500 million kg of $PM_{2.5}$. These same trends were seen for the 2027–2039 period with higher percentages. The 2040–2049 and 2050–2060 modeling periods show that the Supply Driven Alternative performs the worst, followed by the No Action Alternative. For the 2027–2039, 2040–2049, and 2050–2060 modeling periods, the Maximum Operational Flexibility and Enhanced Coordination Alternatives have over 90 percent of the futures below 500 million kg of $PM_{2.5}$.

The Lake Powell vulnerability plots show that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are vulnerable to similar conditions, and only about 10 percent of the traces include droughts this dry or drier; therefore, these alternatives are the least vulnerable. The CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven Alternatives are above the median 10-year-average Lees Ferry flow and are the most vulnerable in a 10-year drought.

For the Average Flow Category (12.0–14.0 maf), Davis Dam and Parker Dam perform similarly under the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both the LB Priority and Pro Rata approaches) Alternatives perform the worst and have the highest variability. The No Action and Basic Coordination Alternatives perform the best for Davis Dam and Parker Dam. For Glen Canyon Dam and Hoover Dam, the Average Flow Category shows the No Action and Basic Coordination Alternatives perform the worst, and the No Action Alternative has the highest variability. The Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches) perform the best.

A general discussion of the effects of climate trends on lake reservoirs is discussed in **TA 7**, Air Quality; however, due to uncertainty, these effects cannot be determined for each specific alternative. In addition, **TA 3**, Hydrologic Resources, details the lake reservoir elevations for the flow categories and alternatives.

3.8 Biological Resources – Fish and Other Aquatic Species

3.8.1 Affected Environment

The affected environment consists of the Colorado River and its tributaries from Lake Powell downstream to the SIB. This area supports a diverse assemblage of aquatic organisms that form a complex food web that sustains both native and nonnative fish populations. Native fish include federally threatened and endangered species, range-wide conservation species (species under a multi-state conservation agreement), BLM sensitive species, and those covered under the LCR MSCP (Reclamation 2024b). Nonnative fish species, including cold-water and warmwater sportfish, are also present (see **Attachment 1** in **TA 8**, Biological Resources – Fish and Other Aquatic Species, for detailed life histories and distributions). River flow variations and dam operations, especially those related to Glen Canyon Dam, significantly influence aquatic habitats within the channel, shorelines, backwaters, and tributary mouths. Several invasive species have been inadvertently introduced, including quagga mussels (*Dreissena bugensis*), New Zealand mud snails (*Potamopyrgus antipodarum*), and various fish and aquatic plants (Reclamation 2024b).

Native Fish Species

Historically, the Colorado River supported 35 native fish species; of these, 26 were unique to the Basin (Miller 1955, 1958; Valdez and Muth 2005). Today, only seven native species remain within the analysis area: humpback chub, razorback sucker, Colorado pikeminnow, bonytail, bluehead sucker, flannelmouth sucker, and speckled dace (FWS 2002; Valdez and Carothers 1998; Brockdorff 2022); see **Tables 8-1** and **8-2** in **Section TA 8.1**, Affected Environment. Of these species, the humpback chub, razorback sucker, Colorado pikeminnow, and bonytail are ESA listed as endangered or threatened (Bestgen et al. 2020; Minckley et al. 2003).

Nonnative Fish Species

The presence of nonnative species has both beneficial and detrimental effects on the aquatic community. Although certain nonnative fish species support sport and recreational fisheries, they also pose substantial risks to native communities by increasing predation, competing for resources, and altering habitat conditions (NPS 2021a). High-risk species include smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), flathead catfish (*Pylodictis olivaris*), and brown trout (*Salmo trutta*). Other nonnatives, such as rainbow trout (*Oncorhynchus mykiss*), largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), and striped bass (*Morone saxatilis*), are common and managed as sportfish (see **Table TA 8-2** in **Section TA 8.1**, Affected Environment) (UDWR 2023).

Native and nonnative aquatic species are summarized across the following three Colorado River reaches: Lake Powell, Glen Canyon Dam to Pearce Ferry, and the LCR MSCP reaches (Lake Mead to Imperial Dam).

Lake Powell

Lake Powell supports 6 native fish species and at least 17 nonnative species (see **Table TA 8-2** in **Section TA 8.1**, Affected Environment) (Smith 2022). Native fish species include razorback sucker, bluehead sucker, flannelmouth sucker, and bonytail. Razorback suckers are present in the reservoir, and bonytail are stocked, with recent signs of reproduction. Colorado pikeminnow are rare, mainly occurring in inflows from the Colorado and San Juan Rivers. Flannelmouth and bluehead suckers are widespread, while speckled dace inhabit shorelines and tributaries.

Recent low water levels have created new riverine habitats, influencing fish movement and connectivity (Cathcart et al. 2018; Ahrens 2022). Water temperature and stratification dynamics affect habitat suitability and downstream releases from Glen Canyon Dam (Hueftle and Stevens 2001). Limnological data indicate changes in phytoplankton biomass and community composition, with potential implications for harmful algal blooms and water quality (Deemer et al. 2023). Invasive bivalves, including Asian clam (*Corbicula fluminea*) and quagga mussel, also alter plankton communities and threaten ecosystem health (USGS 2024).

Glen Canyon Dam to Pearce Ferry

This reach spans nearly 300 miles and is shaped by altered flow regimes and habitat diversity (Valdez and Ryel 1995). Native species include razorback sucker, humpback chub, bluehead sucker, flannelmouth sucker, and speckled dace (see **Table TA 8-2** in **Section TA 8.1**, Affected Environment) (NPS 2023b). Humpback chub also persists in tributaries such as the Little Colorado River and Havasu Creek. Nonnative species include rainbow trout, brown trout, bass, sunfish, catfish, and minnows (Shollenberger et al. 2025). Smallmouth bass and green sunfish recruitment are influenced by temperature and flow management (Reclamation 2025b). Invasive species, such as quagga mussels and New Zealand mud snails, are present but face environmental constraints (NPS 2015).

LCR MSCP Reaches (Lake Mead to Imperial Dam)

Lake Mead supports a unique, naturally recruiting population of razorback sucker and a diverse fish community, including humpback chub near the Colorado River confluence (see **Table TA 8-2** in **Section TA 8.1**) (Rogers et al. 2023). Downstream reaches (Lake Mohave, Lake Havasu, and Parker Strip) are managed for sportfish and native fish conservation, with stocking and augmentation programs for razorback sucker and bonytail (LCR MSCP 2024). Habitat creation, genetic monitoring, and pond rearing improve survival and recruitment (Kesner et al. 2012; Reap et al. 2023; Bestgen et al. 2020). Invasive species, including quagga mussel, crayfish, Asian clam, and snails, continue to threaten water quality and native biota (USGS 2025c).

3.8.2 Environmental Consequences

Methodology

To evaluate future management strategies for the Colorado River, the DMDU modeling approach was used. This method systematically compared five alternatives and a baseline, representing different river flow and reservoir management strategies across a wide range of plausible futures. The analysis relied on visual tools, such as conditional box plots, robustness heat maps, and vulnerability bar plots, to summarize how each alternative could affect aquatic habitats, water quality, and fish populations. Details on the issue-specific methodology are described in **Section TA 8.2.1**, Methodology, in **TA 8**, Biological Resources – Fish and Other Aquatic Species.

Impact Analysis Area

The impact analysis area includes the Colorado River corridor from the full-pool elevation of Lake Powell downstream to the SIB, including various habitats and reaches described in the analysis area.

Assumptions

Modifications in the quantity, timing, temperature, and quality of water released from Glen Canyon Dam and Hoover Dam through the lower Colorado River are expected to influence fish habitats, distributions, and population abundances; this is because changes in flow can alter available habitat and affect species' numbers. Reduced flows are likely to affect backwaters and riverine habitats that support native fish; reduced flows may also affect known spawning sites for razorback sucker. The analyses use models such as the CRSS and smallmouth bass population models developed in collaboration with various agencies. For efficiency of analysis, some LCR MSCP reaches are combined due to the limited presence of special status species or unique management needs. Ongoing fisheries management practices by agencies within the Colorado River Basin are expected to remain consistent into the future.

Impact Indicators

Key impact indicators included the abundance and location of razorback sucker larvae, elevation thresholds where spawning habitats may become limited, and annual monitoring data for sportfish catches. Additional indicators were habitat availability and abundance of native fish species by life stage, changes in backwater area at different flow stages, and shifts in the distribution and abundance of Colorado pikeminnow, razorback sucker, and humpback chub with expanded inflows. The analyses also considered electrofishing and angler catch rates for rainbow trout and brown trout in the Lees Ferry sub-reach, changes in fish habitat and population numbers based on dam releases and flow conditions, and the suitability and area of razorback sucker spawning sites at different flow stages.

Other indicators included changes to Colorado pikeminnow and razorback sucker critical habitat in the Lake Powell inflows, changes to razorback sucker critical habitat in Lake Mead, increased smallmouth bass escapement through Glen Canyon Dam, downstream distribution, salinity concentration changes, and the effects of lower reservoir elevations on shoreline spawning and nursery habitat for razorback sucker. Maintaining reservoir elevation to protect the power pool at Lake Powell (above 3,490 feet) and Lake Mead (above 1,000 feet) and to preserve the Piute Farms Rapid (above 3,666.5 feet) and the Pearce Ferry Rapid (above 1,090 feet) was also important. The analyses further considered reduced abundance and distribution of fish species, water quality impacts, and reduced wetland area and river inflow habitat.

Issue 1: Lower reservoir elevations have reduced lake habitat and extended the inflows of the Colorado River and San Juan River by approximately 35 miles each. How will changes in flow affect the quantity and quality of lake, wetland, and riverine inflow habitats?

Recent declines in Lake Powell's reservoir elevations have transformed aquatic habitats by reducing traditional lake environments and expanding riverine inflows for both the Colorado River and San Juan River. This shift benefits endangered fish like the Colorado pikeminnow and razorback sucker by increasing the length of exposed riverine critical habitat (see **Tables TA 8-3** and **TA 8-4** in

Section TA 8.2.2, Environmental Consequences, Issue 1); however, the shift also raises questions about the future quality and quantity of habitats available for lake, wetland, and riverine species. Lake elevations also affect fish passage at Piute Farms Waterfall on the San Juan River, which blocks both nonnative fish from entering upstream habitats and native fish from returning to their historical riverine environments. Lower reservoir levels increase the risk of smallmouth bass entrainment at Glen Canyon Dam, potentially raising predation and competition pressures on downstream native fish, while also reducing lake habitat for sportfish and affecting recreational fishing (see **Table TA 8-5** in **Section TA 8.2.2**, Environmental Consequences, Issue 1).

Critical thresholds for habitat inundation and fish passage are central to management decisions. For example, a Lake Powell elevation above 3,598 feet inundates critical habitat for Colorado pikeminnow and razorback sucker in the Colorado River inflow, while elevations above 3,600 feet do the same in the San Juan River inflow (see **Tables TA 8-3** and **TA 8-4** in **Section TA 8.2.2**). **Figures TA 8-1** and **TA 8-3** in **Section TA 8.2.2** show the percentage of futures for each alternative in which lake elevations remain below these thresholds, preserving critical riverine habitat. Conversely, **Figures TA 8-2** and **TA 8-4** in **Section TA 8.2.2** illustrate the vulnerability of alternatives to exceeding these thresholds and losing habitat value. Only the No Action Alternative is projected to increase critical habitat length, while all other alternatives decrease it to varying degrees, with the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches) showing the largest reductions.

Lake elevations below 3,666.5 feet also sustain the function of Piute Farms Waterfall as a fish barrier in the lower San Juan River (see **Figures TA 8-5** and **TA 8-6** in **Section TA 8.2.2**), influencing both native and nonnative fish movement. Availability of shoreline habitat, which supports sportfish and native species, is quantified in **Table TA 8-5** in **Section TA 8.2.2**. The table shows how habitat area changes with lake elevation. Maintaining Lake Powell above 3,570 feet reduces the risk of smallmouth bass entrainment at Glen Canyon Dam (see **Figure TA 8-7** in **Section TA 8.2.2**), while elevations below this threshold in more than 20 percent of years increase entrainment risk and potential impacts on native fish (see **Figure TA 8-8** in **Section TA 8.2.2**). Overall, the analysis demonstrates that reservoir management alternatives have implications for habitat extent, fish passage, and species survival by altering the extent and connectivity of lake, wetland, and riverine inflow areas.

Issue 2: Changes in water quantity, release timing, temperature, and quality from Glen Canyon Dam downstream through the Grand Canyon to Pearce Ferry.

The Colorado River reach from Glen Canyon Dam to Lake Mead has experienced notable ecological changes due to dam operations that alter water quantity, timing, temperature, and quality. These changes affect both native fish species, such as the threatened humpback chub and endangered razorback sucker, and nonnative species, such as smallmouth bass and rainbow trout (see **Table TA 8-1** in **Section TA 8.1.1**, Native Fish Species). The survival and abundance of these native species are closely linked to flow regimes and habitat availability, while sportfish and other native fish are also affected by altered river conditions. As Lake Powell's elevation drops, the warm surface water (epilimnion) aligns with the dam's penstocks, increasing the risk that nonnative fish, especially smallmouth bass, will be entrained and released downstream. Entrainment modeling (Eppehimer et al. 2025) shows that the risk rises sharply below 3,530 feet, becomes difficult to control below 3,510 feet, and only declines when water is released through the bypass at elevations below 3,490 feet. Maintaining reservoir elevations above 3,570 feet at the start of the year, or above 3,600 feet, is predicted to substantially reduce the risk of smallmouth bass and other nonnative species entering downstream habitats. Warmer water releases as elevations decline also facilitate the reproduction and establishment of warmwater, nonnative fish, which increase threats to ESA-listed and native species.

Smallmouth bass population growth (lambda) and entrainment risk are the lowest under the Enhanced Coordination and Maximum Operational Flexibility Alternatives, with these alternatives most consistently keeping lambda values below 1 and annual entrainment below 50 adults (see **Figures TA 8-21** and **TA 8-23** in **Section TA 8.2.3**, Environmental Consequences, Issue 2). Vulnerability analysis (see **Figures TA 8-22** and **TA 8-24** in **Section TA 8.2.3**) shows that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are less likely to fail under the driest hydrologic scenarios, compared with other alternatives. Overall, the Enhanced Coordination and Maximum Operational Flexibility Alternatives provide the most robust protection against undesirable warming and smallmouth bass invasion, while the No Action Alternative, Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches), and CCS Comparative Baseline are more vulnerable under drought and low-flow conditions.

HFEs from Glen Canyon Dam, as described in **TA 5**, Geomorphology and Sediment, are used to build sandbars for geomorphic and habitat benefits; however, HFEs may have limited direct benefits for native fish like humpback chub. HFEs are short-term releases that do not significantly affect Lake Powell's elevation or long-term flows. HFEs are primarily intended for sediment management, not fish populations. The main biological impact is on fish in the Grand Canyon, especially rainbow trout in the Lees Ferry sub-reach, where HFEs and flow regulation have improved spawning habitat and survival rates.

Water quality, including dissolved oxygen and water temperature, is also critical for fish health. Dissolved oxygen levels fluctuate with reservoir elevation and are presented and analyzed in **Figures TA 6-9** and **TA 6-8** in **TA 6**, Water Quality. The results of the model show that the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain higher dissolved oxygen during droughts, supporting fish survival (EPA 1986).

Water temperature was evaluated using DMDU conditional box plots, robustness heat maps, and vulnerability bar plots (see **Figures TA 8-9** through **TA 8-20** in **Section TA 8.2.3**, Environmental Consequences, Issue 2). These analyses show that water temperatures generally increase downstream and vary depending on flow conditions and management alternatives. At Lees Ferry, the Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust in maintaining cooler water temperatures, with the Enhanced Coordination Alternative meeting the preferred minimum performance in 71 percent of futures and the Maximum Operational Flexibility Alternative in 59 percent of futures (see **Figure TA 8-10** in **Section TA 8.2.3**). This is critical for rainbow trout survival, as temperatures above 20 °C increase trout mortality and favor native fish and smallmouth bass. Under drier conditions, all alternatives show an increase in temperature threshold exceedance, although the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently perform the best.

At the Little Colorado River and Havasu Creek confluences, the Enhanced Coordination and Maximum Operational Flexibility Alternatives also limit the number of days when water temperatures exceed 16 °C; this would reduce smallmouth bass spawning risk while potentially restricting humpback chub reproduction (see **Figures TA 8-14** and **TA 8-17** in **Section TA 8.2.3**, Environmental Consequences, Issue 2). In contrast, the No Action Alternative, Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches), and CCS Comparative Baseline are less robust, often resulting in more days above critical temperature thresholds. At Pearce Ferry, all alternatives perform similarly for humpback chub growth thresholds (12 °C); however, the Enhanced Coordination and Maximum Operational Flexibility Alternatives still perform better at limiting days above 16 °C (see **Figure TA 8-20** in **Section TA 8.2.3**).

Issue 3: Lower reservoir elevations have reduced lake habitat and extended river inflows, including about 30 miles on the Colorado River and 20 miles on the Virgin River, with similar extensions observed at Las Vegas Bay, Echo Bay, and other locations. How will these inflow changes affect the quantity and quality of lake, wetland, and riverine inflow habitats?

The lower Colorado River Basin, stretching from Lake Mead to the SIB, has experienced significant ecological shifts due to variable reservoir elevations and tributary inflows. These changes have directly affected the quantity and quality of lake, wetland, and riverine habitats for both native and nonnative fish species. When Lake Mead elevations are low, shoreline habitat for sportfish and razorback sucker decreases, while riverine inflow habitats on the Colorado River, Virgin River, and other tributaries expand. This expansion can alter designated critical habitat for razorback sucker and influence the distribution of native species, such as humpback chub, flannelmouth sucker, and razorback sucker. However, as Lake Mead rises, available spawning and nursery habitats for razorback sucker may become limited due to inundation.

A key natural feature, Pearce Ferry Rapid, serves as a barrier to both native and nonnative fish movement. When Lake Mead is above 1,090 feet, the rapid is submerged and no longer blocks nonnative fish from moving upstream into the Grand Canyon; this increases the risk of nonnative species invasion. Conversely, if the lake falls below 1,000 feet, hydropower generation becomes compromised. These thresholds are critical for both ecological function and water resource management.

To evaluate these impacts, fish population and habitat monitoring data were combined with lake elevation analyses. Two primary thresholds were identified: (1) elevations above 1,090 feet, where Pearce Ferry Rapid no longer prevents nonnative fish passage, and (2) very low lake elevations that could dry out razorback sucker spawning areas. Conditions outside the 2008–2024 Interim Guidelines period represent untested scenarios for the Lake Mead fish community. If the lake remains within historical bounds, ongoing fishery management and stocking practices are expected to sustain the existing community (see **Figure TA 8-25** in **Section TA 8.2.4**, Environmental Consequences, Issue 3).

Modeling results show that maintaining Lake Mead below 1,090 feet preserves current ecological conditions by limiting nonnative fish expansion into the Grand Canyon. When this threshold is maintained for 90 percent of the time, nonnative expansion is minimized. Under modeled futures, the No Action Alternative and the CCS Comparative Baseline are the most robust, achieving this threshold in 58 percent and 51 percent of scenarios, respectively. While higher lake levels could support native fish movement and spawning, they also increase the risk of nonnative species invasion and competition.

Razorback sucker spawning habitat was assessed using lake elevation data from 2008 to 2024, with the lowest recorded elevation at 1,040.92 feet in July 2022 still supporting the current fish assemblage. **Figure TA 8-27** (see **Section TA 8.2.4**, Environmental Consequences, Issue 3) shows the proportion of futures where each alternative maintains Lake Mead above this minimum for at least 90 percent of months through 2060. The No Action Alternative (13 percent of futures) and the CCS Comparative Baseline (23 percent) are less robust, while the Basic Coordination Alternative (44 percent), Enhanced Coordination Alternative (57 percent), Maximum Operational Flexibility Alternative (56 percent), Supply Driven Alternative (LB Priority approach; 58 percent), and Supply Driven Alternative (LB Pro Rata approach; 69 percent) perform best. The Supply Driven Alternative (LB Pro Rata approach) is the most effective at sustaining adequate lake elevation and habitat for the existing fish community.

Further analysis indicates that extended droughts could lower Lake Mead below historical ranges, reducing available nursery and spawning habitat. **Figure TA 8-28** (see **Section TA 8.2.4**, Environmental Consequences, Issue 3) illustrates that the No Action Alternative is most vulnerable to such declines (with a driest 20-year average flow of 13.1 maf), followed by the CCS Comparative Baseline (12.6 maf), while the Supply Driven Alternative (LB Pro Rata approach) is least vulnerable (11.1 maf). Despite potential reductions in habitat during prolonged low-elevation periods, if future lake levels stay within the 2008–2024 range, the fish community is expected to remain relatively stable.

Issue 4: How would modifications in water quantity, timing, temperature, and quality released from Hoover Dam affect the lower Colorado River, including LCR MSCP reaches 2 through 6 (Hoover Dam to Davis Dam and Lake Mohave, Davis Dam to Parker Dam and Lake Havasu, Parker Dam to Cibola Gage, Cibola Gage to Imperial Dam and Imperial Reservoir, and Imperial Dam to the NIB)?

Water released from Hoover Dam plays a key role in shaping aquatic habitats throughout the LCR MSCP reaches 2–6, extending to the SIB. The LCR MSCP prioritizes the protection of backwaters, isolated ponds, predator-free refuges, and marsh habitats, especially where ESA-listed species like razorback sucker, bonytail, flannelmouth sucker, and desert pupfish occur. If future water release patterns remain within the historical 2008–2024 range, the composition and dynamics of fish communities are expected to remain stable. However, significant changes in the timing, quantity, or temperature of releases could flood or dry critical spawning, nursery, and refuge habitats, potentially harming native and ESA-listed fish. Reduced flows could also enable nonnative species, such as flathead catfish, to move upstream, increasing predation and competition for native fish.

Lake Mohave, Lake Havasu, and other downstream areas closely mirror Hoover Dam release patterns, and modeling indicates there are no major differences among the management alternatives in this regard. Thus, Hoover Dam releases serve as a reliable indicator for downstream habitat conditions. **Figure TA 8-29** (see **Section TA 8.2.5**, Environmental Consequences, Issue 4) shows that all alternatives keep releases within the historical range for more than 92 percent of the 2027–2060 period, with the No Action Alternative and the CCS Comparative Baseline being the most robust (62 percent and 51 percent, respectively). The Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative perform less well but still maintain historical flows most of the time. **Figure TA 8-30** (see **Section TA 8.2.5**) illustrates monthly release variability, showing that while most alternatives are similar in wet years, the No Action Alternative and CCS Comparative Baseline maintain higher releases during droughts, which could accelerate declines in Lake Mead elevations, whereas the Supply Driven Alternative (LB Pro Rata approach) provides reduced but steadier releases, helping to keep Lake Mead above critical levels and supporting habitat stability in the LCR MSCP reaches. As long as Hoover Dam releases remain within historical boundaries, downstream habitats and fish communities are likely to remain similar to conditions observed during 2008–2024.

Summary Comparison of Alternatives

The analysis compares several proposed alternatives for the Colorado River downstream of Glen Canyon Dam using hydrologic modeling, ecological indicators, temperature thresholds, and assessments of ecosystem vulnerability and resilience. A full summary of those findings can be found in **Figure TA 8-31** in **Section TA 8.2.6**, Summary Comparison of Alternatives. Key findings show that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are most robust in maintaining cooler water temperatures, maintaining higher dissolved oxygen levels, and controlling nonnative species like smallmouth bass. However, they may restrict native fish spawning and growth. In contrast, the No Action Alternative and the CCS Comparative Baseline better preserve riverine habitats above Lake Powell and prevent upstream movement of nonnative fish from Lakes Powell and Mead; this would benefit endangered species such as Colorado pikeminnow and razorback sucker but reduce lake habitat for sportfish.

The effects of water quality, particularly dissolved oxygen, were also evaluated. The Enhanced Coordination and Maximum Operational Flexibility Alternatives sustain healthier conditions for fish during droughts. For Lake Mead and downstream habitats, the No Action Alternative and the CCS Comparative Baseline maintain lower lake elevations that help contain nonnative fish; however, they may also limit native fish access to new habitats. Most alternatives support stable flows and fish communities downstream of Hoover Dam, though the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives are less robust in maintaining desirable release patterns. Each alternative involves trade-offs between supporting native endangered species, controlling nonnative fish, and maintaining recreational fisheries.

3.9 Vegetation Including Special Status Species

3.9.1 Affected Environment

This analysis categorizes vegetation into marsh, woody riparian, and upland habitat types (collectively referred to as terrestrial habitats) throughout the analysis area, which includes Lake Powell, Glen Canyon Dam to Lake Mead, Lake Mead, and Hoover Dam to the SIB. For additional information on the affected environment, including a list of special status species, please reference **TA 9**, Vegetation Including Special Status Species, and **Attachment 1**, Special Status Plant Species, in **TA 9**. **Table TA 9-1** in **Section TA 9.1**, Affected Environment, provides the approximate acreages of marsh, woody riparian, and upland habitats by reach.

Marsh habitats occur in areas that are consistently flooded and are typically found in the transition zone between open water and upland ecosystems. Marsh vegetation is sensitive to drought on short timescales, seasonally to annually, and has been found to decrease in cover, species diversity, and productivity when water availability shifts from perennial to intermittent (Stromberg et al. 2005, 2007; Freidman et al. 2022). Woody riparian habitats occur where water is consistently available and periodic flooding occurs. Woody riparian vegetation typically has deeper root systems capable of accessing alluvial groundwater and is not dependent on surface water flows (Stromberg et al. 2013). This vegetation type is sensitive to drought on longer timescales, on an annual to decadal scale, depending on the species (Shafroth et al. 2002). Upland habitats occur in areas without consistent water availability, where vegetation depends on precipitation.

Lake Powell. Short-term and long-term fluctuating water elevations influence Lake Powell's shoreline vegetation. The median annual water elevation fluctuation during the Interim Guidelines period (between 2008 and 2024) was 30.17 feet (see **Figure TA 9-1** in **Section TA 9.1**, Affected Environment). The drought-induced drawdown of Lake Powell since 2011 has reduced the lake's perimeter and exposed approximately 59,000 acres of formerly submerged land (Root and Jones 2022). Recently exposed sites below full pool of Lake Powell shows a higher percentage and cover of nonnative species, with prickly Russian thistle (*Salsola tragus*) being extremely abundant (Arens 2023). However, native shrubs are outcompeting nonnative plants on sites that have been exposed for more than 3 years; these shrubs are providing diverse ecosystems, including hanging gardens and cryptobiotic crusts, where natural flow patterns are reestablishing (Arens 2023). Two special status plant species are present in the Lake Powell reach and could be affected by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

Glen Canyon Dam to Lake Mead. Marsh, woody riparian, and upland habitats from Glen Canyon Dam to Lake Mead are influenced by the peak magnitudes, daily fluctuations, and seasonal patterns of river flows. Most evidence indicates that vegetation composition, structure, distribution, and function are closely tied to ongoing Glen Canyon Dam operations (Reclamation 2016; Palmquist et al. 2023). Marsh and woody riparian vegetation have expanded in this reach since Glen Canyon Dam was completed in 1963 (Sankey et al. 2015). The greatest area of vegetation expansion between 2002 and 2013 was woody riparian vegetation on sandbars in the active channel (Durning et al. 2021). The availability of water at low river elevations from consistent base flows can promote vegetation establishment, whereas prolonged periods of peak flow may inhibit vegetation establishment. When inundation frequency increases by 5 percent or more, vegetation expansion was unlikely to occur (Sankey et al. 2015).

Twenty special status plant species are present in the Grand Canyon to Lake Mead reach and could be affected by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

Lake Mead. Similar to Lake Powell, short- and long-term fluctuations in water elevation affect Lake Mead's shoreline vegetation. The median annual water elevation fluctuation between 2008 and 2024 was approximately 15 feet (see **Figure TA 9-3** in **Section TA 9.1**). The drawdown of Lake Mead from 1998 to 2011 reduced the lake's perimeter by more than 400 kilometers (250 miles) and exposed more than 61,776 acres of formerly submerged land (Engel et al. 2014). Long-term fluctuations allow the establishment of woody riparian vegetation, including the nonnative and invasive tree tamarisk (*Tamarix* spp.); however, as lake levels continue to fall, tamarisk may begin to show drought stress and mortality when water levels fall below their roots.

Overall, native species cover has been found to be greatest overall on surfaces that have been exposed for a longer period of time (Engel et al. 2014). Native vegetation at Lake Mead has been positively influenced by defoliation from the tamarisk leaf beetle (*Diorhabda* spp.) (beetle). Twenty-one special status plant species are present in the Lake Mead reach and could be affected by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

Hoover Dam to the SIB. The LCR MSCP planning area identifies 14 land cover types, including five woody riparian types that are divided into multiple structural types. The marsh land cover type is divided into seven compositional types based on plant composition and vegetation structure (Reclamation 2004; see **Table TA 9-2** in **Section TA 9.1**). Since the beetle's release in 2006, its range has expanded downstream from Lake Mead along the lower Colorado River; by 2019, large beetle populations were detected along the Imperial stretch of the lower Colorado River. In 2020, beetles were present, and defoliation was documented in or around all LCR MSCP study areas (Reclamation 2021). In 2024, beetles were documented to the SIB (McLeod and Pellegrini 2021; Mahoney et. al 2022; RiversEdge West 2025).

In 2024, Reclamation contracted RiverRestoration.Org to map backwater areas (water, marsh, and non-marsh) in the LCR MSCP planning area and to conduct a change analysis between the 2024 effort and a 2000 backwater mapping effort (RiverRestoration.Org 2025). The study found an overall decrease in marsh area between Davis Dam and Morelos Dam from 2000 to 2024. Nine special status plant species are present in the Hoover Dam to SIB reach and could be influenced by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

3.9.2 Environmental Consequences

Figures referenced in this section and a description of how to interpret the results of the analysis are provided in **Section TA 9.2**.

Methodology

There are no long-term vegetation monitoring datasets available for Lake Powell, Lake Mead, or Hoover Dam to the SIB that would support quantitative habitat modeling, as was done for the Glen Canyon Dam to Lake Mead section; therefore, a qualitative approach was used to determine the predicted differences in marsh and woody riparian vegetation among the alternatives. As noted in **Section 3.9.1**, Affected Environment, marsh and woody riparian vegetation are affected by water level fluctuations on short (annual) and long (5-year) timescales. Therefore, changes in water elevation over 1-year and 5-year periods were used as proxies to represent potential changes to marsh and woody riparian vegetation. To determine the changes in water elevation under each alternative, the CRSS model was applied within the DMDU framework to show maximum variability within 1 year and over 5 years in the robustness heat map figures. A 5-year period was selected as a conservative estimate for impacts from long-term water level fluctuations. Refer to

Section 3.2, Analysis Methods, for a general explanation on how to interpret DMDU robustness heat maps.

The DMDU calculations are based on the alternatives meeting a preferred minimum performance, defined by a threshold applied to model output values and a frequency over time. If a modeled future meets both the threshold and frequency, it is considered a successful future. For Lake Powell vegetation, the thresholds correspond to the median observed variability in water elevation over 1 year (for marsh vegetation) and 5 years (for woody riparian vegetation), which represent historical conditions. The CCS Comparative Baseline data displayed on each figure represent the modeled outcome if current management strategies are continued into the future. This information is included for comparative purposes between the alternatives and the modeled future of the analysis area.

Since vegetation can tolerate a range of environmental conditions, failing to meet the threshold criteria once over the full modeling period is not necessarily detrimental to the habitat's establishment or growth over the long term. Therefore, the analysis focuses on the number of times that the model meets the criteria over a 10-year window for marsh vegetation and a rolling 10-year window for woody riparian vegetation.

The GCMRC conducted hydrologic niche modeling for several species on the fixed-site sandbars for each alternative and used these models to estimate the acres of habitat suitability for each species (Butterfield and Palmquist 2026). The data used for this modeling were collected from 2014 to 2019 (Palmquist et al. 2018a) and can be accessed in the associated data release (Palmquist et al. 2022). In addition to habitat suitability, changes to native species richness, proportion native cover, and total native vegetation cover were estimated by combining the modeled habitat suitability.

The hydrologic niche modeling includes HFEs. For a detailed analysis of frequency and duration of HFEs under each alternative, see **TA 5**, Geomorphology and Sediment. Figures presented for this reach are conditional box plots (refer to **Section 3.2**, Analysis Methods, for a general explanation on how to interpret conditional box plots). The hydrologic niche modeling results used to create these figures can be accessed in the associated data release (Butterfield and Palmquist 2026).

As with Lake Powell, changes in water elevation from historical conditions were used as a proxy to determine potential impacts on marsh and woody riparian vegetation under each alternative for Lake Mead. The same methods for Lake Mead were used as described for Lake Powell.

As with Lake Powell and Lake Mead, the change in water elevation was used as a proxy to determine potential impacts on marsh and woody riparian vegetation under each alternative for the Hoover Dam to SIB reach. However, for this reach, water releases were used to represent changes from historical conditions rather than water elevation. Releases from Hoover Dam, Davis Dam, and Parker Dam were modeled, as releases from these dams determine the amount of water available downstream. Davis Dam and Parker Dam were found to have similar trends as Hoover Dam; therefore, only Hoover Dam results are discussed in detail. The impacts as described in the Hoover Dam to SIB section apply to the entire reach.

Impact Analysis Area

The Lake Powell reach includes Lake Powell up to full pool (water surface elevation 3,700 feet). The Glen Canyon Dam to Lake Mead reach extends from Glen Canyon Dam (RM -15.6) to RM 240. The Glen Canyon Dam to Lake Mead reach begins at Glen Canyon Dam, includes the Colorado River through Grand Canyon, and ends where Lake Mead at full pool occurs at RM 240. The analysis area for this reach extends to the 45,000-cfs modeled stage elevation, corresponding to the maximum controlled flood releases under the current HFE protocol; the analysis area is considered the active floodplain of the Colorado River in this reach under LTEMP (Reclamation 2016)**.** The section from Glen Canyon Dam to Lake Mead is divided into the following three sub-reaches to account for vegetation community changes (Palmquist et al. 2018b): Marble Canyon (RM -15.6 to RM 60), Eastern Grand Canyon (RM 60 to RM 161), and Western Grand Canyon (RM 161 to RM 240).

The Lake Mead reach extends from RM 240 in the Grand Canyon to Hoover Dam. The analysis area for this reach includes the full pool of Lake Mead (water surface elevation 1,229 feet). The Hoover Dam to SIB reach is aligned with the LCR MSCP planning area. As described in **TA 8**, Biological Resources – Fish and Other Aquatic Resources, there are seven reaches within the LCR MSCP planning area. For vegetation analysis, the analysis area includes LCR MSCP reaches 2 through 7 (Reclamation 2004). Reach 1 in the LCR MSCP planning area includes Lake Mead up to the full pool, which is addressed separately as Lake Mead. The analysis area includes the full pool of Lake Mohave and Lake Havasu and the Colorado River's historical floodplain.

Assumptions

The assumptions used for the analysis of impacts are provided in **Section TA 9.1**, Affected Environment.

Impact Indicators

The following impact indicators were used:

- A change in the median and interquartile ranges from modeled historical conditions (Glen Canyon Dam to Lake Mead reach)
- Changes in water fluctuations within a single year compared with historical conditions (Lake Powell, Lake Mead, and Hoover Dam to SIB reaches)
- Changes in water fluctuations in the preceding 5 years compared with historical conditions (Lake Powell, Lake Mead, and Hoover Dam to SIB reaches)

Issue 1: How would changes in the management of the Colorado River impact vegetation, including special status species

Lake Powell. For all alternatives, increased variability in the first decade (2027–2039; **Figure TA 9-7** in **TA 9**, Vegetation Including Special Status Species), which is indicated by a lower percentage of futures meeting the level of performance, may result in decreased marsh vegetation due to more frequent dewatering and inundation. In later decades (2040–2049 and 2050–2060; **Figure TA 9-7**), when variability becomes closer to historical conditions for the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative (as indicated by a higher percentage of futures meeting the level of performance), marsh vegetation may reestablish to a similar historical extent under those alternatives.

In the first decade, cover of prickly Russian thistle may increase due to the increased area of upland habitat created during water elevation fluctuations. Cover of prickly Russian thistle would be expected to decrease in the later decades if variability also decreases; this would reduce areas vulnerable to invasive species establishment on an annual basis. Native vegetation could reestablish over time, particularly in areas exposed for more than 3 years (Arens 2023).

For the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative under the Critically Dry Flow (4.46–10.0 maf), Lake Powell has a modeled WY minimum median elevation of approximately 3,565 feet and 3,549 feet, respectively (see **Table TA 3-4** in **Section TA 3.2**, Environmental Consequences, in **TA 3**, Hydrologic Resources); these median elevations are 7 feet above and 9 feet below, respectively, the minimum 2024 water elevation of 3,558 feet (see **Figure TA 3-1** in **Section TA 3.1**, Affected Environment). Under the Average Flow Category (12.0–14.0 maf), Lake Powell has a WY modeled minimum median elevation of approximately 3,630 and 3,624 feet for the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative, respectively (see **Table TA 3-4** in **Section TA 3.2**); these median elevations are approximately 72 and 66 feet higher than the minimum 2024 water elevation. This suggests that Lake Powell may rise under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative under all but the critically dry modeled conditions.

If water elevations gradually rise with similar levels of variability to historical conditions (**Figure TA 9-7**), marsh vegetation is expected to continue to reestablish along the new water line over time. If water elevations rise, some of the side canyons that were exposed as Lake Powell receded may reflood, which would inundate the native plant communities that had reemerged.

For all other alternatives, Lake Powell would remain near current elevations or decrease under all but the wet modeled conditions. If water elevations stay the same or gradually fall with similar variability to historical conditions (**Figure TA 9-7**), marsh vegetation may reestablish to a similar extent along the new water line over time. Under these alternatives, plant communities in the side canyons would remain exposed.

Whether water elevations rise, fall, or remain the same, if variability resembles historical conditions under the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative in the later decades (**Figure TA 9-7**), marsh vegetation is expected to continue to reestablish along the new water line over time. For the alternatives that have more variability than historical conditions (**Figure TA 9-7**), marsh vegetation may reestablish to a smaller extent along the new water line over time. Where variability eliminates or prevents the establishment of marsh habitat, woody riparian or upland habitat may become the dominant habitat type.

The trends and type of impacts on woody riparian vegetation are the same as those described for marsh vegetation for Lake Powell (**Figures TA 9-7** and **TA 9-8**). The Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative would have vegetation most similar to historical conditions in the later decades (2040–2060; **Figure TA 9-8**).

Also similar to marsh vegetation, whether water elevations rise, fall, or stay the same, if there are similar levels of variability to historical conditions under the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative in the later decades (**Figure TA 9-8**), then woody riparian vegetation is expected to continue to reestablish along the new water line over time. For alternatives that have more variability than historical conditions (**Figure TA 9-8**), woody riparian vegetation may reestablish to a smaller extent along the new water line over time. Where variability eliminates or prevents the establishment of woody riparian habitat, upland habitat may become the dominant habitat type.

Glen Canyon Dam to Lake Mead Suitable Habitat Area – Marsh. Marsh vegetation includes bulrushes (*Schoenoplectus* spp.), rushes (*Juncus* spp.), field horsetail (*Equisetum arvense*), and common reed (*Phragmites australis*) (**Figure TA 9-9**).

Across all three sub-reaches, under the Wet Flow Category (16.0–31.11 maf), the overall trends among alternatives are similar. Across all alternatives, there is less suitable habitat available for marsh species than under modeled historical conditions (see the dashed line on **Figure TA 9-9**).

For Marble Canyon and Eastern Grand Canyon, under the Average Flow Category (12.0–14.0 maf) and the Dry Flow Category (10.0–12.0 maf) conditions, the interquartile ranges for all alternatives overlap the modeled historical conditions (dashed line), indicating that the amount of habitat suitable for marsh species would stay similar to existing conditions under these scenarios. Under the Critically Dry Flow Category (4.46–10.0 maf), the Maximum Operational Flexibility Alternative and Supply Driven Alternative interquartile ranges are completely above the reference line, indicating that suitable habitat for marsh species may increase under the critically dry conditions for those alternatives. Under the No Action Alternative, Basic Coordination Alternative, and Enhanced Coordination Alternative, the interquartile ranges overlap the reference line and could therefore increase or decrease suitable habitat for marsh species.

In the Western Grand Canyon, under the Moderately Wet Flow Category (14.0–16.0 maf), there may be less suitable habitat for marsh species than under modeled historical conditions for all alternatives. Under the Average Flow Category (12.0–14.0 maf), the Enhanced Coordination Alternative has a wider interquartile range than the other alternatives, though ultimately all alternatives overlap the modeled historical reference line. This suggests that the Enhanced Coordination Alternative may lead to more or less suitable habitat for marsh species. Given that most of the interquartile range is below the modeled historical conditions, there may be less suitable habitat for marsh species under average conditions under the Enhanced Coordination Alternative.

Under the Dry (10.0–12.0 maf) and the Critically Dry Flow Categories (4.46–10.0 maf), all alternatives overlap or are above the modeled historical conditions, indicating that suitable habitat for marsh species may remain similar to or increase in Western Grand Canyon, compared with historical conditions. Under the Critically Dry Flow Category (4.46–10.0 maf), the CCS Comparative Baseline has the largest interquartile range. This means it is harder to predict how the CCS Comparative Baseline would respond under those conditions. Given that most of the interquartile range is below the modeled historical conditions, there may be less suitable habitat for marsh species.

The decrease in suitable habitat for marsh species under the Moderately Wet Flow Category (14.0–16.0 maf) for all sub-reaches and all alternatives may occur because higher water levels may reduce the overall available terrestrial habitat in the river's active channel (Sankey et al. 2015). The similarity or increase in suitable habitat for marsh species under the Critically Dry Flow Category (4.46–10.0 maf) and the Dry Flow Category (10.0–12.0 maf) for all sub-reaches and all alternatives may be because decreasing water levels increase the amount of exposed shoreline habitat.

Glen Canyon Dam to Lake Mead Suitable Habitat Area – Woody Riparian. Woody riparian vegetation includes seepwillow (*Baccharis* spp.), arrowweed (*Pluchea sericea*), honey mesquite (*Prosopis glandulosa*), and coyote willow (*Salix exigua*) (**Figure TA 9-10**).

Across all three sub-reaches, all alternatives show similar trends: The wide and generally similar interquartile ranges suggest woody riparian suitable habitat would respond in a similar way across all alternatives.

Similar to marsh habitat, under the Wet Flow Category (16.0–31.11 maf), there is less suitable habitat for woody riparian species, as indicated by the interquartile ranges and medians remaining below the modeled historical conditions (the dashed line on **Figure TA 9-10**). Under the Critically Dry Flow Category (4.46–10.0 maf), the interquartile ranges extend far above and below the modeled historical conditions for all alternatives except for the No Action Alternative, indicating the variability is too high to predict whether there would be more or less suitable habitat for woody riparian species under these alternatives. The No Action Alternative remains above the modeled historical conditions for all three sub-reaches. This may be because under the No Action Alternative, there would be less water available, compared with the other alternatives, and thus more exposed shoreline that can support woody riparian species.

Similar to marsh habitat, the decrease in suitable habitat for woody riparian species under the Moderately Wet Flow Category (14.0–16.0 maf) for all sub-reaches and all alternatives may be because higher water levels reduce the overall available terrestrial habitat (Sankey et al. 2015). However, suitable habitat for woody riparian species may increase under the Critically Dry (4.46–10.0 maf) and Dry Flow (10.0–12.0 maf) Categories; this expansion may occur near river level on areas recently exposed by lower water levels. Suitable habitat for both woody riparian and marsh species may overlap in these recently exposed areas. These habitat types would compete in habitats near the river. In areas near the top of the active floodplain, decreasing water levels may provide an opportunity for an increase in upland habitat due to disconnection from the river.

Glen Canyon Dam to Lake Mead – Native Species Richness. Native species richness (**Figure TA 9-11**) includes all habitat types and does not distinguish between marsh, woody riparian, and upland. Across all three sub-reaches, all alternatives show similar trends: The wide and generally similar interquartile ranges suggest native species richness would respond in a similar way across all alternatives.

Under the Wet Flow Category (16.0–31.11 maf) and Critically Dry Flow Category (4.46–10.0 maf) modeled conditions, the interquartile ranges for most alternatives are generally at or below the modeled historical conditions (dashed line). This suggests that at the natural flow extremes, species richness may decrease. Under the Moderately Wet (14.0–16.0 maf), Average (12.0–14.0 maf), and

Dry (10.0–12.0 maf) Flow Categories, the 50th percentile is below the modeled historical conditions, but the 75th percentile is generally above the modeled historical conditions. Since most of the interquartile range is still below the modeled historical conditions, native species richness may decrease under wet, average, and dry flow conditions. However, given the large interquartile ranges, it is difficult to predict how each alternative may respond.

Species richness at the fixed-site sandbars declined from 2014 to 2019. This trend was driven by low species richness in 2019 (Palmquist et al. 2023). The low species richness in 2019 was likely caused by the HFE that occurred in fall 2018 and the lack of monsoon precipitation in summer 2019. Native species richness may decrease under the wet modeled conditions because HFEs will be a more frequent occurrence. Native species richness also may decrease under the critically dry conditions due to a lack of precipitation. Under all conditions, a combination of these hydrologic and climatic factors may be driving the variable interquartile ranges.

Glen Canyon Dam to Lake – Mead Proportion Native Species Cover. The proportion native species cover (**Figure TA 9-12**) includes all habitat types and does not distinguish between marsh, woody riparian, and upland vegetation. Across all three sub-reaches, all alternatives show similar trends: The generally wide and similar interquartile ranges in each sub-reach suggest the proportion of native cover would respond in a similar way across all alternatives.

Under the Wet Flow Category (16.0–31.11 maf), the interquartile ranges for all alternatives are generally at or below the modeled historical conditions (see the dashed line on **Figure TA 9-12**). This suggests that under the Wet Flow Category (16.0–31.11 maf), the proportion of native cover may decrease.

Under the Critically Dry Flow Category (4.46–10.0 maf), the 75th percentile is above the modeled historical conditions, under all alternatives. This suggests that under the critically dry modeled conditions, the proportion native cover may stay similar to historical conditions or increase under most alternatives, particularly in Marble Canyon. However, given the large interquartile ranges, it is difficult to predict how each alternative may respond.

In Marble Canyon and Eastern Grand Canyon under the Moderately Wet (14.0–16.0 maf), Average (12.0–14.0 maf), and Dry (10.0–12.0 maf) Flow Categories, the 50th percentile is below the modeled historical conditions for most alternatives, but the 75th percentile is at or above the modeled historical conditions for all alternatives. Since most of the interquartile range is still below the modeled historical conditions, the proportion native cover may stay similar or decrease under moderately wet, average, and dry flow conditions in Marble Canyon and Eastern Grand Canyon. However, given the large interquartile ranges, it is difficult to predict how each alternative may respond.

In Western Grand Canyon, under moderately wet, average, and dry modeled conditions, the interquartile ranges are generally at or below the modeled historical conditions. This suggests that under moderately wet, average, and dry model conditions in Western Grand Canyon, the proportion of native cover may decrease.

Encroachment of riparian vegetation into the exposed active channel and into the bare sand of sandbars has been found to be driven by seepwillows, which are a native species (During et al. 2021). The proportion of native species cover may decrease under the Wet Flow Category (16.0–31.11 maf) due to the lack of bare sand available for native species, particularly seepwillows, to colonize. The proportion of native cover may increase under the critically dry modeled conditions because of more available sand.

Glen Canyon Dam to Lake Mead – Annual Total Vegetation Cover. Annual total vegetation cover (**Figure TA 9-13**) includes all habitat types and does not distinguish between marsh, woody riparian, and upland. Across all three reaches, all alternatives show similar trends: The generally similar and overlapping interquartile ranges suggest annual total vegetation cover would respond in a similar way across all alternatives.

Under the Wet (16.0–31.11 maf) and Moderately Wet (14.0–16.0 maf) Flow Categories, there is less annual total vegetation cover, shown as the interquartile ranges at or fully beneath the modeled historical conditions (dashed line). Under the Critically Dry (4.46–10.0 maf) and Dry (10.0–12.0) Flow Categories, the interquartile ranges are partially or fully above the modeled historical conditions. Under the Critically Dry Flow Category (4.46–10.0 maf), the medians are also at or above the modeled historical conditions. This indicates there may be more annual total vegetation cover under the dry and critically dry conditions.

Similar to the discussions above under *Suitable Habitat Area*, the decrease in annual total native cover under the wet and moderately wet modeled conditions for all sub-reaches and all alternatives may be because higher water levels reduce the overall available terrestrial habitat (Sankey et al. 2015). Conversely, annual total vegetation cover may increase under the critically dry and dry modeled conditions, likely on areas recently exposed by lower water levels.

Lake Mead. For all alternatives, the increased variability from historical conditions in the first decade (2027–2039; **Figure TA 9-14**) of the analysis may result in decreased cover of marsh vegetation. In later decades (2040–2049 and 2050–2060; **Figure TA 9-14**) when variability becomes closer to historical conditions for the Basic Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative, marsh vegetation may reestablish to a similar extent. Similar to Lake Powell, when conditions are more variable, cover of nonnative species, such as prickly Russian thistle, may increase; if variability decreases, then native cover may reestablish.

As shown in **Figure TA 3-11** (see **Section TA 3.2**), the interquartile ranges for the WY minimum of all alternatives for the Average (12.0–14.0 maf) and Dry (10.0–12.0 maf) Flow Categories are large, making it uncertain whether Lake Mead will increase, decrease, or remain the same under those conditions. Under the Wet Flow Category (16.0–31.1 maf), the interquartile ranges are smaller, and the medians for all alternatives, except the No Action Alternative, are above the 2024 WY minimum of 1,061 feet (**Figure TA 3-11**; see **Section TA 3.2**); this suggests that Lake Mead would rise under the wet conditions.

Similar to Lake Powell, whether water elevations rise, fall, or remain the same, if there are similar levels of variability to historical conditions under the Basic Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative in the later decades

(**Figure TA 9-14**), marsh vegetation is expected to continue to reestablish along the new water line over time. For alternatives with greater variability than historical conditions (**Figure TA 9-14**), marsh vegetation may reestablish to a smaller extent along the new water line over time. Where variability eliminates or prevents the establishment of marsh habitat, woody riparian or upland habitat may become the dominant habitat type.

Similar to Lake Powell, the first decade of modeling for woody riparian vegetation is influenced by historical data (**Figure TA 9-15**). Across the full modeling period, all alternatives are more variable than historical conditions; however, the Basic Coordination and Maximum Operational Flexibility Alternatives are notably more similar to historical conditions than the other alternatives. For the first decade (2027–2039; **Figure TA 9-15**), the Basic Coordination Alternative is most similar to historical conditions. The later decades (2040–2049 and 2050–2060; **Figure TA 9-15**) show the same trend as the trend in **Figure TA 9-14**, with the Basic Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative being most similar to the historical variability.

For the Basic Coordination Alternative, the moderately similar variability to historical conditions in the first decade (2027–2039; **Figure TA 9-15**) may result in more cover of woody riparian vegetation, compared with the other alternatives. In later decades (2040–2049 and 2050–2060; **Figure TA 9-15**), when variability becomes more similar to historical conditions for the Basic Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives, woody riparian vegetation may reestablish to a similar extent as existing conditions. Where variability eliminates or prevents the establishment of woody riparian habitat, upland habitat may become the dominant habitat type.

Figures TA 9-14 and **TA 9-15** suggest that annual variability in Lake Mead water elevations may be higher, especially in the early decade of the modeling period; however, the variability on a 5-year basis may overall be closer to historical conditions, generally benefiting woody riparian vegetation.

Hoover Dam to the SIB. For all alternatives, the increased variability from historical conditions in the first decade (2027–2039; **Figure TA 9-16**) may result in decreased marsh vegetation cover. In later decades (2040–2049 and 2050–2060; **Figure TA 9-16**) when variability becomes closer to historical conditions for the Basic Coordination and No Action Alternatives, marsh vegetation may reestablish to a similar extent. Where variability eliminates or prevents establishment of marsh habitat, woody riparian or upland habitat may become the dominant habitat type.

During the 2007 Interim Guidelines period, the annual volume of the Colorado River below Hoover Dam averaged 9.185 maf (**Section TA 3.1**). For all alternatives under the Average (12.0–14.0 maf) and Dry Flow Categories (10.0–12.0 maf), the interquartile ranges of the modeled annual volume are below 9.185 maf (**Table TA 3-21** and **Figure TA 3-27** in **Section TA 3.2**). This suggests that the annual flow volume below Hoover Dam may decrease under all alternatives under the Average (12.0–14.0 maf) and Dry (10.0–12.0 maf) Flow Categories. The 2007 Interim Guidelines reduced the average annual releases from Hoover Dam by approximately 1.014 maf from prior operating guidelines (**Section TA 3.1**).

As described in **Section TA 9.1**, the recent change analysis indicates marsh vegetation generally decreased from 2000 to 2024 (RiverRestoration.Org 2025). If water releases decrease with higher levels of variability, compared with historical conditions (**Figure TA 9-16**), marsh vegetation is expected to continue to decrease over time under average and dry conditions. If water releases decrease with similar levels of variability as historical conditions (**Figure TA 9-16**), marsh vegetation is expected to decline at a rate similar to existing conditions under average and dry conditions.

For all alternatives, increased variability from historical conditions in the first decade (2027–2039; **Figure TA 9-17**) may result in decreased woody riparian vegetation cover due to inconsistent water availability. In later decades (2040–2049 and 2050–2060; **Figure TA 9-17**), there is increased variability from historical conditions for all alternatives; however, the Basic Coordination and No Action Alternatives are notably closer to historical conditions than the other alternatives. This increased variability may result in decreased riparian vegetation cover under all alternatives, but to a lesser extent under the Basic Coordination Alternative and No Action Alternative. Where variability eliminates or prevents woody riparian habitat establishment, upland habitat may become the dominant habitat type.

Summary Comparison of Alternatives

Table TA 9-4 in **Section TA 9.2** provides a comparison of alternatives that are most and least similar to historical conditions for each reach.

For Lake Powell marsh and woody riparian vegetation, the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative would result in vegetation most similar to historical conditions. The Maximum Operational Flexibility Alternative would also result in vegetation most similar to historical conditions for Lake Mead's marsh and woody riparian vegetation. However, for the Hoover Dam to the SIB reach, the Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative would result in vegetation least similar to historical conditions, which would result in larger changes in vegetation, compared with historical conditions, for that reach. Similarly, the Basic Coordination Alternative would result in conditions least similar to historical conditions for Lake Powell, but would be closest to historical conditions for Lake Mead and Hoover Dam to the SIB. This suggests that no single alternative would result in vegetation similar to historical conditions across all reaches.

For all reaches, multiple alternatives provide variability more similar to historical conditions than the CCS Comparative Baseline, except for the Hoover Dam to SIB reach, where only the Basic Coordination Alternative would result in variability more similar to historical conditions. This suggests that a change in management from current strategies would benefit a large portion of the analysis area; however, it would not benefit the Hoover Dam to SIB reach unless the Basic Coordination Alternative is selected.

For the Glen Canyon Dam to Lake Mead reach, the alternative that would result in vegetation most similar to historical conditions depends strongly on whether initial conditions are wet or dry. Across all alternatives, all sub-reaches, and all evaluated criteria (the suitable habitat area, native species richness, proportion of native species cover, and annual total vegetation cover), the interquartile ranges often overlap. When the interquartile ranges overlap, it is difficult to determine whether one alternative is truly different from another. Therefore, no single alternative emerged as the best or worst for retaining vegetation similar to historical conditions.

Under all alternatives for Lake Powell, Lake Mead, and Hoover Dam to the SIB, the first decade would experience more variability, which would result in a reduction in marsh, woody riparian, and upland habitat, compared with historical conditions. All alternatives would see conditions return closer to historical conditions in the second and third decades, which may result in vegetation reestablishing to a similar extent. Where variability eliminates or prevents the establishment of marsh, woody riparian, or upland habitat, there may be a shift to one of the other habitat types.

3.10 Terrestrial Wildlife Including Special Status Species

3.10.1 Affected Environment

This section provides an overview of the general terrestrial wildlife typically found within marsh, woody riparian, and upland habitats in the analysis area, as described in **Section 3.9**, Vegetation Including Special Status Species, including invertebrates, amphibians, reptiles, birds, and mammals. This section also includes special status species, which are defined here as those listed as BLM sensitive species in the overlapping Arizona, California, Utah, and Nevada BLM field offices; species covered under the LCR MSCP; and species listed as threatened, endangered, or proposed for listing by the FWS (BLM 2017, 2018, 2019, 2023; LCR MSCP 2022; FWS 2025). **Attachment 1** in **TA 10**, Terrestrial Wildlife Including Special Status Species, provides a table of the species considered in this document, including their listing status, the river reaches they typically inhabit, and the habitat types most important to their life histories. **Attachment 1** in **TA 10** was developed with input from cooperating agencies and local experts. A full description of the wildlife and special status species that use each of the habitat types is provided in **Section TA 10.1**, Affected Environment, in **TA 10**.

In addition to analyzing the impacts on wildlife in the analysis area as defined in **Section 3.9**, Vegetation Including Special Status Species, impacts are also evaluated for the LCR MSCP conservation areas. These areas were established to provide habitat for species listed under the ESA or that may become listed under the ESA and that use habitat along the Colorado River from Lake Mead down to the SIB (LCR MSCP 2025). The Colorado River in this area has been highly modified by several dams and water diversions, which have affected the growth and establishment of marsh and woody riparian habitat (see **Section 3.9.1**, Affected Environment). The LCR MSCP Habitat Conservation Plan (HCP) and subsequent ESA consultations identified the impacts on marsh, woody riparian, upland, and backwater habitats predicted from existing and anticipated future river operations, and the program established the conservation areas and off-river land acquisitions to mitigate for these losses and provide reliable suitable habitat for wildlife (LCR MSCP 2025). There are 18 conservation areas aimed at conserving 27 species, with a goal of creating 5,940 acres of cottonwood/willow, 1,320 acres of honey mesquite, 568 acres of marsh, and 484 acres of backwater habitats. In addition to the conservation areas, several wildlife refuges and lands managed for wildlife and recreation are present below Hoover Dam. These include Havasu National Wildlife Refuge, Bill Williams River National Wildlife Refuge, Cibola National Wildlife Refuge, Imperial

National Wildlife Refuge, Gooseflats Wildlife Area, Lake Mead NRA, and Mittry Lake Wildlife Management Area.

Section 3.9, Vegetation Including Special Status Species, describes the marsh, woody riparian, and upland habitat types, which are used in this section to determine the affected environment and environmental impacts on wildlife, including special status species. For additional information on the wildlife species considered in this analysis by habitat type, please reference **Section TA 10.1**, Affected Environment, in **TA 10.2**, Terrestrial Wildlife Including Special Status Species.

3.10.2 Environmental Consequences

Methodology

This Terrestrial Wildlife section relies on the outcomes of the vegetation analysis, the methodology for which is outlined in the Methodology subsection of **Section 3.9.2**, Environmental Consequences.

Impact Analysis Area

The analysis area is the same as described in the Impact Analysis Area subsection of **Section 3.9.2**, Environmental Consequences.

Assumptions

- Upland wildlife species, including special status species, that do not rely directly on the Colorado River or on woody riparian and marsh vegetation influenced by elevation or flows are not included in the impact analysis because changes in operations would not impact these species.
- Impacts on wildlife, including special status species, are driven by impacts on vegetation.

Impact Indicators

- For terrestrial wildlife species using marsh habitat, changes in water fluctuations within a single year compared with historical conditions
- For terrestrial wildlife species using woody riparian habitat, changes in water fluctuations in the preceding 5 years compared with historical conditions
- For terrestrial wildlife species using upland habitat, changes in water fluctuations over either the preceding single year or preceding 5 years compared with historical conditions

Issue 1: How would changes in the management of the Colorado River impact terrestrial wildlife species habitat availability, including special status species?

Lake Powell

As discussed in **Section 3.11.2**, Environmental Consequences, Lake Powell's surface water elevations fluctuate on a short-term (annual) and long-term (5-year) scale, which causes changes in water availability and which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife, including special status species (hereafter collectively referred to as wildlife), that currently use the Lake Powell analysis area have adapted to these changing conditions over the past 60 years.

Under all alternatives, modeling indicates a greater range of variability in Lake Powell's surface elevations compared with historic conditions for both marsh and woody riparian habitat in the first decade (2027–2039) (**Figure TA 9-7** and **Figure TA 9-8** in **TA 9**, Vegetation Including Special Status Species). As described in **Section TA 9.2**, Environmental Consequences, in **TA 9**, Vegetation Including Special Status Species, this greater variability would result in changes in the vegetation extent compared with existing conditions and could decrease vegetation cover. While Lake Powell would continue to support at least some upland, marsh, and woody riparian habitat, the location of conditions suitable to support each of these habitat types is likely to change. Areas that currently support marsh, woody riparian, or upland habitat could transition to one of the other habitat types.

With increased variability, wildlife would have to adapt to changing habitat availability on a larger scale than under historical conditions. For those species capable of moving long distances, such as large mammals, bats, birds, and some amphibians, reptiles, and invertebrates, this change in habitat availability would likely have fewer long-term impacts, provided that suitable habitat is available within their dispersal or migratory range. Habitat transitions could also result in the range expansion or contraction of some species, including into new reaches, as they adapt to changing habitat availability. For less mobile species, such as some small mammals, amphibians, reptiles, and invertebrates, the transition from one habitat type to another may impact foraging, breeding, or sheltering behaviors, which can impact survival and reproduction. Decreased survival and reproduction on a large scale can result in a decreased population size. Smaller local populations are more vulnerable to environmental stochasticity, which can lead to even greater reductions in population size and the risk of local extirpation (Rosenzweig 1995).

During the second decade (2040–2049) and third decade (2050–2060), modeling indicates a range of variability more similar to historical conditions under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative compared with the other alternatives as well as compared with the first decade (2027–2039; **Figure TA 9-7** and **Figure TA 9-8** in **TA 9**, Vegetation Including Special Status Species). This would result in habitat variability similar to what is currently on the landscape; wildlife would need to adapt to changing habitat conditions at the same scale as historical conditions. For all other alternatives, variability would remain high in the second and third decades, and wildlife would continue to need to adapt to changing habitat availability on a larger scale compared with historical conditions.

In addition to the annual and 5-year changes in water elevation, modeling indicates Lake Powell would gradually rise in elevation over time under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative in all but the critically dry modeled conditions (**Table TA 3-4** and **Figure TA 3-1** in **TA 3**, Geomorphology and Sediment). This would result in a shift of marsh and woody riparian vegetation along the new shoreline over time. The rise in water elevation would result in a marginal loss of upland habitat, but is not likely to impact wildlife that use marsh or woody riparian habitat, as the shift would be gradual enough for vegetation to continue to reestablish along the new shoreline. Under all other alternatives, modeling indicates water levels would remain the same or decrease in elevation. Similarly, vegetation would reestablish along the lower shoreline as the water elevations change over time. As water elevations lower, the distance to water for upland species would increase. However, given the ability for vegetation to adapt to changing water levels, this change in water elevation, either to a higher elevation under the

Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative or to a similar or lower elevation under all other alternatives, would not likely impact foraging, breeding, or sheltering behaviors for wildlife. Except for the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative, in all but the critically dry modeled conditions, the lowering of the water elevation in Lake Powell could increase the potential for harmful algal blooms, which could impact wildlife directly through increased toxicity exposure or indirectly through reductions in habitat quality and quantity.

While monarch butterflies (*Danaus plexippus plexippus*) primarily use woody riparian habitat for migration, they also use marsh and upland habitat regularly. Given the shifting availability of marsh, woody riparian, and upland habitat, and the ability to use features from all three habitat types, monarch butterflies are likely to be able to find suitable habitat under all alternatives in the Lake Powell analysis area. Species-specific impacts will be addressed in future ESA Section 7 Biological Opinions (BOs).

Glen Canyon Dam to Lake Mead

Similar to Lake Powell, the Glen Canyon Dam to Lake Mead reach experiences fluctuating water levels that cause changes in water availability, which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife in the Glen Canyon Dam to Lake Mead analysis area have had to adapt to these changing conditions in the past.

As shown in **Figure TA 9-9** and **Figure TA 9-10** in **TA 9**, Vegetation Including Special Status Species, marsh and woody riparian habitat across all three sub-reaches of the Glen Canyon Dam to Lake Mead reach is modeled to respond similarly under all alternatives, and the wide interquartile ranges in **Figure TA 9-10** in **TA 9**, Vegetation Including Special Status Species, indicate that future acreages of woody riparian habitat are difficult to predict. Under the wet modeled conditions, less suitable habitat for marsh and woody riparian species is modeled for all alternatives than under modeled historical conditions. Under the critically dry modeled conditions, more suitable habitat for woody riparian species is modeled under the No Action Alternative compared with modeled historical conditions, whereas modeled variability under the other alternatives is too wide to interpret whether there would be more or less suitable habitat for marsh or woody riparian vegetation. Therefore, the amount of habitat available for wildlife species, including southwestern willow flycatcher (*Empidonax traillii extimus*) and yellow-billed cuckoo (*Coccyzus americanus*), is affected primarily by modeled antecedent conditions rather than by the alternatives. Species-specific impacts will be addressed in future ESA Section 7 BOs.

Similar patterns are apparent for native species richness, proportion of native species cover, and annual total vegetation cover (**Figure TA 9-11**, **Figure TA 9-12**, and **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). Increased species richness, proportion of native species cover, and annual total vegetation cover would be beneficial to wildlife species for foraging and breeding habitat. However, increases in each of these factors are driven by the modeled antecedent conditions rather than by the alternatives, with additional habitat available under the critically dry modeled conditions. This is likely due to encroachment of vegetation into areas exposed by lower water levels.

With potentially decreasing water levels at Lake Powell, the temperature of releases from Glen Canyon Dam could increase, increasing the potential for harmful algal blooms in the Glen Canyon Dam to Lake Mead reach. Harmful algal blooms could impact wildlife directly through increased toxicity exposure or indirectly by reducing habitat quality and quantity.

Lake Mead

Similar to Lake Powell, Lake Mead experiences fluctuating water levels on an annual and 5-year time scale that cause changes in water availability, which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife in the Lake Mead analysis area have had to adapt to these changing conditions in the past.

As described for Lake Powell, the first decade (2027–2039) exhibits higher variability compared with historical conditions under all alternatives, which would result in changes in habitat availability on a larger scale compared with existing conditions (**Figure TA 9-10** and **Figure TA 9-11** in **TA 9**, Vegetation Including Special Status Species). Marsh and woody riparian vegetation is expected to decrease in response to the increase in variability.

Wildlife species that are capable of moving longer distances would be less likely to be affected by increased variability, provided that suitable habitat is available within their dispersal or migratory range. Even for species that are highly mobile, there may be energetic costs to finding suitable habitat in a fragmented landscape if the distance between suitable habitat locations is outside their typical movement patterns. Increased energetic costs can impact survival and reproduction. Species that are less mobile may experience impacts on foraging, breeding, or sheltering behaviors, which can also impact survival and reproduction. Decreased survival and reproduction through increased energetic costs while searching for suitable habitat or through impacts on foraging, breeding, or sheltering behaviors can result in a decreased population size. Smaller local populations are more vulnerable to environmental stochasticity, which can lead to even greater reductions in population size and the risk of local extirpation (Rosenzweig 1995).

Unlike Lake Powell, at Lake Mead the second decade (2040–2049) and third decade (2050–2060) exhibit variability similar to historical conditions for the Basic Coordination Alternative and Maximum Operational Flexibility Alternative, rather than the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative. However, the impacts on wildlife would be the same as described under Lake Powell for the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative. That is, wildlife would need to adapt to changing habitat conditions at a rate more similar to historical conditions under the Basic Coordination Alternative and Maximum Operational Flexibility Alternative and would need to adapt to changing habitat conditions on a larger scale for the remaining alternatives.

As described in **Section TA 9.2**, Environmental Consequences, in **TA 9**, Vegetation Including Special Status Species, for all alternatives, Lake Mead elevations could rise, fall, or remain the same compared with existing conditions under all but the wet conditions (**Figure TA 3-11** in **TA 3**, Geomorphology and Sediment). Similar to Lake Powell, whether the water elevations increase, decrease, or stay the same compared with existing conditions, wildlife would likely be able to adapt to these slower changes and follow the vegetation as it reestablishes along the shoreline. Should water elevations decrease under any of the alternatives, the lowering of the water elevation in Lake Mead could increase the potential for harmful algal blooms, which could impact wildlife directly through increased toxicity exposure or indirectly through reduced habitat quality and quantity.

Listed threatened and endangered species with potential to occur in the Lake Mead analysis area consist of southwestern willow flycatcher, yellow-billed cuckoo, Yuma Ridgway's rail (*Rallus obsoletus yumanensis*), and Mojave desert tortoise (*Gopherus agassizii*). Impacts have been previously assessed in the LCR MSCP HCP, 2007 Final EIS, and 2014 SEIS and associated BOs. Additional ESA Section 7 and Section 10 processes are ongoing, and additional impacts will be disclosed in future BOs and HCPs.

Southwestern willow flycatcher and yellow-billed cuckoo rely on woody riparian habitat, which has modeled increased variability and therefore decreased habitat availability in the first decade compared with historical conditions. These species are capable of moving long distances to access suitable habitat, although southwestern willow flycatchers exhibit local site fidelity and most readily colonize sites that are near existing breeding sites. The loss of suitable breeding habitat in a river reach could result in southwestern willow flycatchers being slow to recolonize the area even if suitable habitat redevelops. For both species, if water levels fluctuate or rise to the extent that habitat is unavailable, then impacts on nesting may occur.

Yuma Ridgway's rails rely on marsh habitat, which may also experience increased variability and therefore decreased habitat availability in the first decade compared with historical conditions. Yuma Ridgway's rails are also capable of moving long distances to access suitable habitat, although the readiness with which they colonize new areas far from established breeding sites is unclear. For all three species, as variability returns closer to historical conditions in the second and third decades for the Basic Coordination Alternative and Maximum Operational Flexibility Alternative, availability of suitable habitat would likely be similar to historical conditions.

Mojave desert tortoises rely on upland habitat. While upland habitat availability is modeled to change under all alternatives in each of the decades, Mojave desert tortoises would have suitable habitat available upslope and would be capable of moving away from rising water levels. Survivorship would depend on the quantity and quality of available forage in the areas they relocate to. As water levels fluctuate, upland habitat loss would be equal to the areas of change unless water fluctuations stabilize and upland vegetation is able to reestablish. Decreased survival and reproduction on a large scale can result in a decreased population size. Smaller local populations are also more vulnerable to environmental stochasticity, which can lead to even greater reductions in population size and the risk of extirpation (Rosenzweig 1995).

As described for Lake Powell, monarch butterflies are likely to find suitable habitat under each alternative and are unlikely to be affected.

Hoover Dam to SIB

Similar to Lake Powell and Lake Mead, the Hoover Dam to SIB reach experiences fluctuating water levels on an annual and 5-year timescale that causes changes in water availability, which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time.

Wildlife in the Hoover Dam to SIB analysis area had to adapt to these changing conditions in the past.

The LCR MSCP HCP and subsequent BOs set habitat creation goals associated with predicted impacts from flow reductions in the LCR MSCP planning area (Reclamation 2004; FWS 2005, 2018, 2022, 2024). A summary of the habitat creation goals and habitat created toward those goals as of 2025 (LCR MSCP 2025) are included as **Table 3-5**. The habitat creation goals are based on the predicted impacts from 2004 to the present. Approximate acres of habitat present in each reach is summarized in **Table TA 9-1** in **TA 9**, Vegetation Including Special Status Species.

Table 3-5
Summary of Habitat Creation Goals and Habitat Acres Created from Lake Mead to the SIB

Habitat Type	Habitat Creation Goal (Acres)	Habitat Created through 2025 (Acres)
Marsh	568	362
Woody riparian (cottonwood-willow and honey mesquite)	7,260	7,000

Sources: For habitat creation goals, Reclamation 2004; FWS 2005, 2022, 2024. For habitat created through 2025, LCR MSCP 2020, 2025.

Table 3-6 and **Table 3-7** detail the number of acres affected, habitat created, and habitat creation commitments. Although it is unknown exactly how many acres of habitat will be affected over the next 30 years, referencing the number of acres affected over the last 20 years, the amount of habitat present in the reaches (**Table TA 9-1** in **TA 9**), and how those acres were mitigated allows for a greater understanding of future implications. Future impacts and habitat creation commitments will be included in future ESA Section 7 BOs and Section 10 HCPs.

As described for Lake Powell and Lake Mead, the first decade (2027–2039) exhibits high levels of variability compared with historical conditions for all alternatives, which would result in changes in habitat availability on a larger scale compared with existing conditions, especially for woody riparian habitat (**Figure TA 9-12** and **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). Marsh and woody riparian habitat are modeled to decrease in the first decade in response to increased variability. Wildlife species that are capable of moving longer distances would not be affected by the increased variability. Similar to Lake Mead, in the Hoover Dam to SIB reach wildlife species could experience decreased population levels or localized extirpations if the increased variability results in increased energy expenditure to find suitable habitat or impacts foraging, breeding, and sheltering behaviors.

Table 3-6
Summary of Federal and Nonfederal Flow-Related Impacts Included in 2004, 2018, 2022, and 2024 HCPs and BOs

Species	Federal and Nonfederal Flow-Related Impacts (Acres)				
ESA Section 7 Consultation	2004 BO and HCP	Additional Impacts in 2018 Biological Assessment, BO, and HCP	Additional Impacts in 2022 Biological Assessment and BO	Additional Impacts in 2024 Biological Assessment and BO	Total
Yuma Ridgway's rail	133	N/A	7	84	224
Southwestern willow flycatcher	1,784	N/A	0	0	1,784
Yellow-billed cuckoo	1,425	N/A	0	0	1,425
Mojave desert tortoise	0	N/A	0	0	0
Northern Mexican gartersnake	N/A	1,081	7	84	1,172

Table 3-7
ESA Section 7 Habitat Creation Commitments and Habitat Created 2005–Present

Species	Section 7 Habitat Creation Conservation and Mitigation Commitments (Acres)					LCR MSCP Land Cover Created for the Species (2005–2025) (Acres)
	2004 BO	2018 BO	2022 BO	2024 BO	Total	All Created and Creditable
Yuma Ridgway's rail	512	N/A	15	41	568	362
Southwestern willow flycatcher	4,050	N/A	0	0	4,050	945
Yellow-billed cuckoo	4,050	N/A	0	0	4,050	2,553
Mojave desert tortoise	230 acres of existing habitat protection	N/A	0	0	230	230 acres purchased

For the Hoover Dam to SIB reach, the Basic Coordination Alternative and No Action Alternative would result in variability most similar to historical conditions in the second decade (2040–2049) and third decade (2050–2060) for both marsh and woody riparian habitats (**Figure TA 9-12** and **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). The impacts on wildlife would be the same as described for Lake Powell and Lake Mead; wildlife would need to adapt to changing habitat conditions at a rate more similar to historical conditions under the Basic Coordination Alternative and No Action Alternative and would need to adapt to changing habitat conditions on a larger scale for the remaining alternatives. This could impact wildlife through changes in foraging, breeding, or sheltering behaviors, which can impact survival and reproductive rates of individuals. Decreased survival and reproduction on a large scale can have population-level impacts.

Under all alternatives, flows from Hoover Dam to SIB are modeled to decrease under average and dry conditions (**Table TA 3-21** and **Figure TA 3-27** in **TA 3**, Geomorphology and Sediment). As described in **Section TA 9.2**, Environmental Consequences, in **TA 9**, Vegetation Including Special Status Species, a recent change analysis found that marsh vegetation decreased from 2000 to 2024 (RiverRestoration.org 2025). With a higher level of variability and decreased releases, marsh vegetation is modeled to continue to decrease over time and be replaced by either upland habitat or woody riparian habitat. Wildlife species that use marsh habitat in the Hoover Dam to SIB reach are modeled to experience greater levels of habitat loss than under historical conditions if future conditions are dry or average. This habitat loss could impact wildlife species' ability to forage, breed, nest, and shelter in the area, causing them to relocate or possibly experience reduced survival rates. The potential for decreased water levels in Lake Mead could also result in water with increased temperatures being released from Hoover Dam. This could increase the potential for harmful algal blooms, which impact marsh and woody riparian vegetation, and could impact wildlife directly through increased toxicity exposure or indirectly through reductions in habitat quality and quantity.

Federal, state, and tribal managed habitat areas, such as Cibola National Wildlife Refuge, depend on water from the Colorado River to ensure functional habitat for wildlife. If water in the river drops below the level at which water is able to properly flow through diversion structures or pumps are able to function, there may be impacts on habitat unless another method is used to transport water to the managed habitat areas. If a prolonged period of dryness occurs, woody riparian and marsh vegetation may begin to desiccate; however, the extent to which this will occur is unknown.

Listed threatened and endangered wildlife species that have the potential to occur in the Hoover Dam to SIB analysis area are southwestern willow flycatcher, yellow-billed cuckoo, Yuma Ridgway's rail, northern Mexican gartersnake, and Mojave desert tortoise. Impacts have been previously assessed in the LCR MSCP HCP, 2007 Final EIS, and 2004 SEIS and associated BOs. Additional ESA Section 7 and Section 10 processes are ongoing, and additional impacts will be disclosed in future BOs and HCPs. Migrant and transient southwestern willow flycatchers and yellow-billed cuckoos could be affected by the general availability of woody riparian vegetation in which they forage and shelter, which is modeled to decrease in the first decade (2027–2039) under all alternatives (**Figure TA 9-12** and **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). In the second (2040–2049) and third (2050–2060) decades, decreased cover of woody riparian vegetation is modeled under all alternatives, but to a lesser extent under the Basic Coordination Alternative and No Action Alternative (**Figure TA 9-12** and **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). Breeding southwestern willow flycatchers have been present in recent years at Topock Marsh, while breeding yellow-billed cuckoos are found in LCR MSCP conservation areas and other restored habitats. Woody riparian vegetation in these areas could be affected by the alternatives if they result in shortage allocation reductions of water deliveries. Reductions in water allocations to the conservation areas could reduce the amount of woody riparian habitat available for yellow-billed cuckoo breeding.

Decreased cover of marsh vegetation may occur in the first decade for all alternatives, which could affect the Yuma Ridgway's rail by reducing the amount of habitat available for breeding, feeding, and sheltering. Under the Basic Coordination Alternative and No Action Alternative, marsh vegetation may reestablish in the second and third decades to an extent similar to recent conditions. However, under dry to average future conditions, marsh vegetation is modeled to decrease over time under all alternatives, which could reduce the amount of habitat available to Yuma Ridgway's rails for breeding, feeding, and sheltering.

The most recent confirmed northern Mexican gartersnake sightings have been in Topock Marsh in the Havasu National Wildlife Refuge. Marsh vegetation at Topock Marsh could be affected by the alternatives if they result in shortage allocation reductions of water deliveries. Northern Mexican gartersnakes are less capable of moving long distances. Should a northern Mexican gartersnake be present in marsh habitat experiencing higher levels of variability that results in the loss of that marsh habitat, as is possible in the first decade under all alternatives, northern Mexican gartersnakes may not be able to find suitable replacement habitat, which could cause local extirpations. In the second and third decades, the Basic Coordination Alternative and No Action Alternative would have conditions more similar to historical conditions, which may support northern Mexican gartersnakes in a manner more similar to existing conditions. Mojave desert tortoises are likely to be able to move to upland habitat as the habitat conditions change over time.

Water levels are modeled to decrease under all alternatives under dry and moderate conditions. This may result in additional upland habitat for the Mojave desert tortoise. As at Lake Powell and Lake Mead, the monarch butterfly is likely to find suitable habitat under each alternative and is unlikely to be affected.

Summary Comparison of Alternatives

Marsh vegetation requires consistent inundation, so when variability increases from historical conditions on an annual scale, marsh vegetation is expected to decrease in extent. Woody riparian vegetation is more resilient to water fluctuations, but when variability increases from historical conditions on a 5-year scale, woody riparian vegetation is expected to decrease in extent. Similarly, if variability decreases on an annual or 5-year scale, marsh, woody riparian, or upland vegetation may increase in extent.

For Lake Powell, the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative would result in wildlife habitat availability most similar to historical conditions (**Table TA 9.2** in **TA 9**, Vegetation Including Special Status Species). The Maximum Operational Flexibility Alternative would also result in wildlife habitat availability most similar to historical conditions for Lake Mead. However, for Hoover Dam to the SIB, the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative would result in wildlife habitat availability least similar to historical conditions, with subsequent impacts on wildlife foraging, breeding, or sheltering behaviors, which can reduce reproduction and survival of individuals. Similarly, the Basic Coordination Alternative would result in wildlife habitat least similar to historical conditions for

Lake Powell, but it would be closest to historical conditions for Lake Mead and Hoover Dam to the SIB. Therefore, no single alternative would result in wildlife habitat availability similar to historical conditions across all reaches. For all reaches, multiple alternatives provide variability more similar to historical conditions than the CCS Comparative Baseline except for the Hoover Dam to SIB reach, where only the Basic Coordination Alternative would result in variability more similar to historical conditions. This suggests that a change in management from current strategies would benefit a large portion of the analysis area but would not benefit the Hoover Dam to SIB reach unless the Basic Coordination Alternative was selected.

Under all alternatives, the first decade (2027–2039) would experience more variability, which would likely result in a reduction in marsh and woody riparian habitat and, therefore, an increase in impacts on wildlife compared with historical conditions. All alternatives would see conditions return closer to historical conditions in the second decade (2040–2049) and third decade (2050–2060), which would likely result in wildlife habitat reestablishing to a similar extent. Where variability eliminates or prevents the establishment of marsh, woody riparian, or upland habitat, there may be a shift to one of the other habitat types.

For the Glen Canyon Dam to Lake Mead reach, the alternative that would result in wildlife habitat availability most similar to historic conditions depends strongly on initial modeled antecedent conditions. Under the dry and critically dry modeled conditions, some differences among the alternatives emerge, presumably because there are greater differences in the lowest flows, the median flows, and peak flows under those conditions. However, across all alternatives, all sub-reaches, and all evaluated criteria (suitable habitat area, native species richness, proportion of native species cover, and annual total vegetation cover), the interquartile ranges of the alternatives often overlap. When the interquartile ranges overlap, it is difficult to say whether one alternative is truly different from another. Therefore, no single alternative emerged as the best or worst for retaining wildlife habitat similar to historic conditions.

For all reaches, a decrease in water elevation or flow could increase water temperatures, which would increase the potential for harmful algal blooms. Harmful algal blooms can cause direct impacts on wildlife through increased toxicity or indirect impacts through decreases in habitat quality and quantity. Under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative, there would be increased water levels in Lake Powell in all but the driest conditions, which would result in the lowest potential for harmful algal blooms. For Lake Mead, all alternatives may result in a lowered elevation, which could increase the potential for harmful algal blooms in Lake Mead and in the Hoover Dam to SIB reach.

3.11 Cultural Resources

3.11.1 Affected Environment

Cultural resources are the physical manifestations of the activities of past or present cultures, including archaeological sites, historic-era buildings and structures, objects, trails, landforms, and other places of traditional, cultural, or religious importance. Cultural resources can be human-made or natural features and are, for the most part, unique, finite, and nonrenewable.

A Class I cultural resources record search was conducted for the study area in Arizona, California, Nevada, and Utah (Tremblay et al. 2024a, 2024b; Eddy et al. 2024; Winslow et al. 2024; Eskenazi 2024). Currently, Reclamation is consulting with the Arizona, California, Nevada, and Utah State Historic Preservation Officers (SHPOs), land managing agencies, affected tribes, and other consulting parties to develop a project-specific programmatic agreement under Section 106 of the National Historic Preservation Act and its implementing regulations (36 CFR 800.14). The development of the programmatic agreement includes the definition of the area of potential effect (APE). The APE often coincides with the NEPA study area; however, as the APE is under development, the Class I search area will be used as the NEPA study area.

The study area for the analysis runs from the northern extent of Lake Powell to the SIB and consists of the Colorado River channel from bank to bank except from Glen Canyon Dam to Lake Mead, where it stretches from canyon rim to canyon rim, as well as a 0.5-mile buffer on either side of the riverbank or canyon rim. For additional information on regulatory considerations, including a detailed summary of Section 106 of the National Historic Preservation Act and its implementing regulations under 36 CFR 800, please reference **Section TA 11.1**, Affected Environment, in **TA 11**, Cultural Resources.

Identification Efforts

Class I efforts included identification of archaeological resources, built environment resources, specially designated cultural resources (National Historic Landmarks [NHLs], National Heritage Areas [NHAs], and National Historic Trails [NHTs]), cultural landscapes, and traditional cultural places (TCPs) within the study area. For additional information on data sources and the types of data collected for each state in the study area, please reference **Section TA 11.1.1**, Identification Efforts, in **TA 11**, Cultural Resources. The Class I records search shows that much of the study area has not been surveyed for cultural resources. Because survey coverage for both reservoirs is very low, there is potential for additional undocumented sites to exist in the study area. It is important to note that resource information presented herein was acquired in August 2023 for the Class I records search, and the 2023 datasets incorporated into the analysis may or may not reflect current agency databases.

This section analyzes impacts on archaeological sites, built environment resources, and specially designated cultural resources. Impacts on tribal resources, tribal perspectives on cultural landscapes, and TCPs (as those of concern are those of Indigenous peoples) are analyzed in **TA 13**, Tribal Resources.

Class I Results

The results of the Class I records search, as summarized below, include archaeological and built environment resources as well as specially designated cultural resources identified in the study area by state. For a more detailed summary on the results of the comprehensive Class I records search for each state, please reference **Section TA 11.1.4**, Class I Results, in **TA 11**, Cultural Resources.

Arizona

The Class I records search identified a total of 4,246 archaeological sites in the study area in Arizona. This number includes both NPS and non-NPS data, accounting for duplicates between the two datasets (see **Table TA 11-1** in **TA 11**, Cultural Resources). Non-NPS data contained 1,246 previously recorded sites in the study area, while 3,158 sites were found in the NPS dataset (see **Table TA 11-2** and **Table TA 11-3** in **TA 11**, Cultural Resources). The NPS dataset represents a wide range of cultural affiliations and site functions across three NPS park units (GCNP, Lake Mead NRA, and Glen Canyon NRA) (see **Table TA 11-4** and **Table TA 11-5** in **TA 11**, Cultural Resources). For the built environment, 46 previously evaluated resources were identified in the study area in Arizona. Of these, 40 are listed in the National Register of Historic Places (NRHP); these non-NHL resources consist of 8 districts (that is, groupings of resources), 24 buildings, 6 structures, 1 object, and 1 site. The remaining 6 resources, all districts, are NRHP-eligible (see **Table TA 11-9** in **TA 11**, Cultural Resources). Additionally, 16 unevaluated but notable built environment resources (5 districts, 1 building, 9 structures, and 1 site) were also identified and may be eligible for the NRHP based on extensive research conducted for the Class I records search (see **Table TA 11-10** in **TA 11**, Cultural Resources).

Specially designated cultural resources identified in the study area in Arizona include eight NHLs, most of which are in GCNP, along with Hoover Dam NHL (also in Nevada) and Yuma Crossing NHL (also in California). Yuma Crossing NHL also encompasses the Yuma Crossing NHA (the only NHA identified in the study area), which is only on the Arizona side of the Colorado River. The Armijo Route of the Old Spanish NHT corridor (also in Utah and Nevada), the Juan Bautista de Anza NHT corridor, and the recently designated Butterfield Overland NHT corridor (both of which also cross into California) also cross the study area in Arizona, although there is no known physical evidence of any of these trails (see **Table TA 11-14** in **TA 11**, Cultural Resources).

California

A total of 493 previously recorded archaeological sites are found within the study area in California (see **Table TA 11-6** in **TA 11**, Cultural Resources) along with 63 built environment resources (three districts, a regional park, and various buildings, structures, roads, and transmission lines) (see **Table TA 11-11** in **TA 11**, Cultural Resources). Yuma Crossing NHL is the only NHL in the study area in California, and there are no NHAs because the Yuma Crossing NHA designation only includes portions of the NHL on the Arizona side of the river. For the portions of the Juan Bautista de Anza NHT and Butterfield Overland NHT that cross the study area in California, there is no physical evidence of original trail segments known to exist.

Nevada

In the Nevada study area, 514 archaeological sites have been previously recorded in the NPS and non-NPS datasets (273 NPS and 241 Nevada Cultural Resources Inventory System only) (see **Table TA 11-7** in **TA 11**, Cultural Resources). Research identified 156 previously documented built environment resources, of which 98 previously identified (districts, individual buildings, structures, sites, and objects) are associated with the construction and ongoing operation of the NRHP-listed Hoover Dam Historic District (also an NHL) on the Nevada side of the Colorado River. In addition to those resources associated with Hoover Dam, there is 1 NRHP-listed structure in Lake Mead NRA (Willow Beach Gauging Station), 26 associated with the development of recreation around Lake Mead and Lake Mohave within Lake Mead NRA, and 3 associated with Davis Dam. The remaining 29 built environment resources include 23 documented on an individual basis (apart from Hoover and Davis Dams and established recreation areas in Lake Mead NRA) and 6 for which no information was available from corresponding archives (see **Table TA 11-13** in **TA 11**, Cultural Resources). Hoover Dam NHL (also in Arizona) and the Mojave Road route of the Old Spanish NHT corridor (also in Arizona and Utah) are the only two specially designated cultural resources in the study area in Nevada. There is no evidence of the Old Spanish NHT identified in the study area.

Utah

A total of 950 previously recorded archaeological sites (229 NPS and 721 non-NPS) were identified in the study area in Utah (see **Table TA 11-8** in **TA 11**, Cultural Resources) along with one built environment resource (NRHP-eligible Hite Crossing Bridge). The Armijo Route of the Old Spanish NHT corridor is the only specially designated cultural resource in the study area in Utah, and, like other NHT corridors, there are no known segments of original trail identified.

3.11.2 Environmental Consequences

Impacts on cultural resources could result from changes in lake levels or river flows from the annual releases. Direct impacts could occur from processes such as wave action and wet/dry cycling as well as other impacts that are immediate in place and time, including visual, auditory, and atmospheric impacts. Indirect impacts are those that occur farther away in distance and/or later in time, such as those from increased ease of access to previously inundated sites. Impacts on cultural resources analyzed in this section only include those impacts resulting from Reclamation's management of annual releases from Glen Canyon and Hoover Dams, which influence reservoir elevations, river flows, and aeolian (wind-borne) transport.

Methodology

Archaeological Resources

Three types of analyses are used to discuss potential impacts on archaeological resources: site counts by elevation and modeled lake elevations, preservation risk modeling developed by the USGS and NPS (Caster et al. 2026), and aeolian transport modeling (Kelley et al. 2026; Salter and Grams 2026), also developed by the USGS. Elevations for all sites identified in the Class I records search compiled for Arizona, California, Nevada, and Utah were calculated and used to identify those sites that are at elevations subject to changes in water levels or flows. For additional information on these three methods, as well as the development of the preservation risk model and the models for wind-deposited sediment, please reference **Section TA 11.2.1**, Methodology, in **TA 11**, Cultural Resources.

Built Environment Resources

No modeling was conducted specifically for built environment resources because these types of resources are much less vulnerable to impacts compared with archaeological resources, which are finite, fragile, and nonrenewable. The most prominent of the built environment resources identified in the study area also constitute critical infrastructure, constructed as part of major Reclamation projects like Glen Canyon Dam, Hoover Dam, and Davis and Parker Dams as well as the smaller dams and the various canals and levee systems in the lowest reaches. Collectively, these facilities are key to Colorado River operations, and none of the alternatives would result in the decommissioning or substantial alteration of such critical infrastructure, so the historic importance of these resources would not be jeopardized. Therefore, it is assumed there would be no direct or indirect impacts on critical infrastructure, and they are not carried forward for analysis.

There are also built environment resources around the reservoirs and immediately along the river corridor—particularly those developed in response to the creation of Lake Powell and Lake Mead or to provide access to or means across the river in the Grand Canyon—that are not considered critical infrastructure for river operations. As such, these types of properties were built in consideration of fluctuating water levels around both the reservoirs and the river corridor. Therefore, impacts on NRHP-listed or -eligible built environment resources would occur where uncharacteristic water levels and river flows exceed historical ranges. For additional information on methodology for built environment resources, please reference **Section TA 11.2.1**, Methodology, in **TA 11**, Cultural Resources.

Specially Designated Cultural Resources

No modeling was undertaken for NHLs, NHAs, or NHTs. The one NHA identified in the study area (Yuma Crossing) coincides with the Arizona portion of the Yuma Crossing and Associated Sites NHL; therefore, it is analyzed as an NHL. There are no confirmed segments of original trail in the study area for the three NHTs. Impacts on specially designated cultural resources (NHLs) would occur where uncharacteristic river flows exceed historical ranges.

Impact Analysis Area

The impacts analysis area consists of the Colorado River corridor from the upper limits of Lake Powell in Utah through the Grand Canyon in Arizona and Lake Mead in Arizona, and from Hoover Dam to the SIB.

Assumptions

- Once a resource has been inundated by a reservoir, being continuously inundated thereafter is more conducive to preservation than repeated cycles of inundation and exposure (that is, wet/dry cycling and wave action).
- Repeating cycles of inundation and exposure of resources by the reservoirs or the river are not conducive to preservation.
- The covering of resources by windblown river-sourced sediment is conducive to preservation.
- Impacts on cultural resources can be characterized based on projected minimum and end-of-year lake elevations for very wet through very dry conditions and river flow volumes.
- Cultural resources that have not been previously inundated would not be inundated under the CCS Comparative Baseline, the No Action Alternative, or any action alternatives (that is, no additional cultural resources above reservoir spillway elevations or current river flows would be inundated).
- The limit of physical impacts on cultural resources by the river is constrained to resources within the river corridor (bank to bank) or within 20 meters (66 feet) of the river.
- Where previous survey coverage is absent within the study area, there may be sites that have not yet been identified that could be affected under the CCS Comparative Baseline, the No Action Alternative, or the action alternatives.

- The Class I records search conducted for the study area in Arizona, California, Nevada, and Utah serves as a representative dataset for the purposes of analysis.
- Lake Mohave and Lake Havasu would be operated under the current rule curve (see **TA 3**, Hydrologic Resources) for target end-of-month elevations at both lakes, which would not be affected by the proposed federal action; therefore, there would be no impacts on cultural resources at these two reservoirs.

Impact Indicators

- Projected monthly and end-of-year lake elevations that may expose cultural resources to damage from wave action, wet/dry cycling, or increased ease of access
- Forecasted changes in river flows that may contribute to erosion and exposure of cultural resources that may expose sites to damage from erosion, wet/dry cycling, or increased ease of access
- Projected availability of sediments along the river that may be transported by wind and deposited on archaeological sites

Issue 1: How will any changes in dam operations affect (1) lake elevations at Lake Powell and Lake Mead and (2) river flows downstream, which may affect cultural resources?

Lakes

This section summarizes the potential for archaeological resources to be exposed and, therefore, experience potential impacts from exposure, using the distribution of previously recorded archaeological sites by elevation and the hydrologic modeling results for Lake Powell and Lake Mead elevations. The following summary incorporates the discussion of hydrologic modeling as presented in **TA 3**, Hydrologic Resources. For additional information on the technical details related to Issue 1, please reference **Section TA 11.2.2**, Issue 1*,* in **TA 11**, Cultural Resources.

Because of the variable survey coverage throughout the study area and the issue of much of the locational data for the sites being recorded prior to modern technology, precise site counts for analysis are not feasible; rather, site counts can be considered a representative sample to understand the overall level of sensitivity in the study area. Representative site counts by elevation were compiled from Class I data using associated elevations based on critical conditions for each lake. For Lake Powell, the associated elevations for critical conditions pertinent this analysis are 3,700 feet (the top of the Glen Canyon Dam spillway) down to 3,490 feet (the minimum power pool) (see **Table TA 3-2** in **TA 3**, Hydrologic Resources). For Lake Mead, these associated elevations for critical conditions pertinent to this analysis are 1,221 feet (the top of the Hoover Dam Spillway) down to 950 feet (the minimum power pool) (see **Table TA 3-5** in **TA 3**, Hydrologic Resources). Archaeological sites identified in the Lake Powell and Lake Mead dataset were distributed by elevation range (see **Table TA 11-15** and **Table TA 11-16** in **TA 11**, Cultural Resources). There are no NRHP-listed or -eligible built environment resources within the critical elevations for Lake Powell (3,700–3,490 feet), but there is one NRHP-eligible district within the critical elevations for Lake Mead (1,221–950 feet): Echo Bay Developed Area in Lake Mead NRA, where a historic-era boat ramp is a contributing element to the district falls between 1,221 and 1,100 feet.

Lake Powell

This section references **Table TA 3-3**, **Table TA 3-4**, and **Figure TA 3-3**, in **TA 3**, Hydrologic Resources. For additional information on these tables and figures as they were incorporated into the analysis of cultural resources, please reference **Section TA 11.2.2**, Issue 1, in **TA 11**, Cultural Resources. In general, where water-level elevations are at reach the top of the Glen Canyon Dam spillway (3,700 feet), all 751 archaeological sites in the Lake Powell dataset (as well as any undiscovered sites below this elevation) would be inundated. Conversely, water levels dropping to minimum power pool could expose up to all 751 archaeological sites (depending on how many of those in the Lake Powell dataset remain above 3,490 feet), leaving them vulnerable to impacts. Additionally, it is important to note that, because some areas at Lake Powell have not been surveyed, any of the modeled scenarios have the potential to impact undiscovered archaeological resources. Sites exposed at higher elevations may be less vulnerable to impacts from wet/dry cycling and wave action, but ease of access to them may increase depending on their location. Elevations for Lake Powell are assessed based on WY minimum and EOWY elevations.

The CCS Comparative Baseline and the No Action, Basic Coordination, Enhanced Coordination, and Maximum Operational Flexibility Alternatives would all perform similarly under the Wet Flow Category (16–31.11 maf) with median elevations around or above 3,680 feet, potentially exposing up to 65 archaeological sites in the 3,700–3,680-foot zone. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would have median elevations of around 3,660 feet, which could potentially leave an additional 397 archaeological sites in the 3,680–3,660-foot zone exposed compared with the other scenarios. Sites exposed at higher elevations may be less vulnerable to impacts from wet/dry cycling and wave action, but ease of access to them may increase depending on their location.

Under average conditions, the sites affected by wet/dry cycling are found at lower elevations in the lake, while sites exposed at higher elevations would see less of those impacts but may have increased ease of access. For the Average Flow Category (12.0–14.0 maf), the modeled scenarios begin to perform differently. Median elevations for the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives would all fall below 3,600 feet but just above 3,580 feet, which could expose up to 274 archaeological sites while inundating the 477 sites identified below this elevation in the Lake Powell dataset. The Supply Driven Alternative would have median elevations just below 3,580 feet, which again would leave up to 274 archaeological sites vulnerable to impacts. The Enhanced Coordination and Maximum Operational Flexibility Alternatives would perform the best, with median elevations at around 3,630 feet and 3,620 feet, respectively, which would inundate the 558 sites found below 6,620 feet and leave a total of 193 sites exposed. Both the Enhanced Coordination and the Maximum Operational Flexibility Alternatives would also have the narrowest interquartile ranges.

As hydrologic conditions become drier, the CCS Comparative Baseline, No Action Alternative, and all action alternatives would struggle to reach key elevations for Lake Powell. For the Critically Dry Flow Category (4.46–10.0 maf), the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven Alternatives would have median elevations as well as interquartile ranges at or below 3,500 feet, dropping below 3,490 feet (the minimum power pool) in some cases. Therefore, at least 274 archaeological sites would be left exposed and vulnerable under the critically dry hydrologic conditions. The elevation where sites are vulnerable to wet/dry cycling and wave action would be the lowest for all modeled scenarios because more of the sites would be above the inundation line as water levels drop, but this modeled scenario would also have the potential for increased ease of access. While the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform better, these two action alternatives also have the potential to expose some of the 477 archaeological sites below 3,580 feet, depending on their elevation. The interquartile ranges for these two alternatives indicate that only the Enhanced Coordination Alternative has the potential to inundate up to 508 archaeological sites, the most of all modeled scenarios under critically dry conditions, as the uppermost limit of this action alternative reaches at least 3,600 feet.

Lake Mead

This section references **Table TA 3-6** and **Table TA 3-7** along with **Figure TA 3-11** in **TA 3**, Hydrologic Resources. For additional information on these tables and figures as they were incorporated into the analysis of cultural resources, please reference **Section TA 11.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources. In general, when water-level elevations are at or above 1,221 feet, all 240 archaeological sites in the dataset would be inundated. Conversely, if water levels drop to 1,081 feet or below, all 240 sites in the Lake Mead dataset would be exposed. Because very little of Lake Mead was surveyed prior to the construction of Hoover Dam in the early 1930s and, as a result, undiscovered archaeological resources are likely to be present in unsurveyed areas, such resources could be affected under any of the modeled scenarios. Elevations for Lake Mead are assessed based on CY minimum and EOCY elevations.

Although conditions as modeled in the Wet Flow Category (16–31.11 maf) for Lake Mead are unlikely, in the Wet Flow Category the CCS Comparative Baseline and No Action Alternative would perform similarly. Median elevations for the CCS Comparative Baseline and No Action Alternative would be around 1,150 feet, exposing a minimum of 173 archaeological sites as identified in the Lake Mead dataset. For the Basic Coordination Alternative, the median CY minimum elevation would be around 1,180 feet, inundating 121 sites and exposing the 119 sites above this elevation, and the EOCY median elevation would be around 1,190 feet, inundating at least 121 sites and those below this elevation in the 1,201–1,181-foot zone. The Enhanced Coordination and Maximum Operational Flexibility Alternatives would perform similarly, with median elevations around 1,210 feet (CY minimum and EOCY). The Supply Driven Alternative would perform the best out of the modeled scenarios in this flow category, with median elevations of around 1,210 feet (CY minimum) and around 1,220 feet (EOCY), potentially inundating at least 121 sites. As discussed above, sites exposed at higher elevations may be less vulnerable to impacts from wet/dry cycling and wave action, but ease of access to them may increase depending on their location.

Similarly to Lake Powell, as conditions for Lake Mead become drier, the sites affected by wet/dry cycling would be found at lower elevations in the lake, while sites exposed at higher elevations would see less of those impacts but may have increased ease of access. In the Average Flow Category (12.0–14.0 maf), the modeled scenarios would have a variable range of performance with respect to minimum CY elevations. The No Action Alternative would perform the most poorly, with median elevations at about 990 feet, which would expose all 240 sites in the Lake Mead dataset. The CCS Comparative Baseline would have higher median elevations than the No Action Alternative at around 1,040 feet but would still leave the 124 known sites vulnerable. The Basic Coordination

Alternative would have median elevations of around 1,080 feet, leaving all but 3 archaeological sites exposed.

The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives all would perform similarly in the Average Flow Category (12.0–14.0 maf), with slight variations in median elevations but greater variability in interquartile ranges. The Enhanced Coordination Alternative would have median elevations of around 1,110 feet, potentially leaving up to 228 sites vulnerable from exposure. The Maximum Operational Flexibility Alternative would have a median CY minimum elevation of about 1,130 feet, protecting at least 23 of the 240 sites in the dataset and those below this elevation in the 1,141–1,121-foot zone, and a median EOCY elevation around 1,140 feet, which would protect 38 sites and leave 202 sites vulnerable. The Supply Driven Alternative would perform the best in the Average Flow Category, with Supply Driven Alternative median elevations under the LB Priority approach of around 1,150 feet, inundating at least 38 sites and those below this elevation in the 1,141–1,161-foot zone, and Supply Driven median elevations under the LB Pro Rata approach of around 1,160 feet, which would inundate 54 more sites and leave 173 sites exposed.

As conditions grow drier, the modeled scenarios would remain the same in relation to one another relative to median CY minimum but would shift downward collectively in elevation about 100 feet in the Critically Dry Flow Category (4.46–10.0 maf). The interquartile ranges would become wider under the critically dry hydrologic conditions, indicating a greater range of variability than in the wetter categories. Under critically dry hydrologic conditions, the elevation where sites are vulnerable to wet/dry cycling and wave action would be the lowest for all scenarios.

In this Critically Dry Flow Category (4.46–10.0 maf), both the No Action Alternative and the CCS Comparative Baseline would have median CY minimum elevations below the minimum power pool of 950 feet. The CCS Comparative Baseline median EOCY elevation would be around 950 feet; however, the No Action Alternative would have median EOCY elevation far below 950 feet. Both would potentially leave all 240 archaeological sites vulnerable from exposure because of these low elevations at and below 950 feet. The Basic Coordination Alternative would fare slightly better, with median elevations of around 990–980 feet but could still leave up to 240 archaeological sites exposed. This is also true of the Enhanced Coordination Alternative, which would have a median CY minimum of just above 1,000 feet and a median EOCY elevation of around 1,020 feet. The Maximum Operational Flexibility Alternative would be similar, with median elevations of around 1,030 feet, which would still leave at least 237 sites vulnerable to impacts.

The Supply Driven Alternative (LB Priority approach) would have similar CY minimum and EOCY median elevations of around 1,030 feet, while the Supply Driven Alternative (LB Pro Rata approach) would have median elevations around 1,050 feet, which is the highest median elevation in the Critically Dry Flow Category (4.46–10.0 maf). Regardless of this, at least 237archaeological sites would still be exposed based on median elevations under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches). The Supply Driven Alternative would have the potential to protect some sites through inundation due to the upper limits of its interquartile ranges, which are around 1,110 feet under the LB Priority approach (inundating at least 12 sites and those sites below this elevation in the 1,121–1,101-foot zone) Supply Driven and around 1,120 feet under the LB Pro

Rata approach, which would inundate another 11 sites (for a total of 23). However, both scenarios would still leave over 215 sites exposed and vulnerable to impacts.

For the Echo Bay Developed Area, any of the modeled scenarios as described above that result in median elevations below 1,100 feet would result in additional exposure of the boat ramp, but this would be outside the NRHP-eligible district boundary. Any of the modeled scenarios resulting in elevations above 1,100 would result in partial or full submersion of the ramp up to 1,221 feet, which would be more likely under the Supply Driven Alternative because the interquartile range under the Supply Driven Alternative (LB Priority approach) would extend just above 1,100 feet and up to around 1,120 feet under the Supply Driven Alternative (LB Pro Rata approach).

Preservation Risk Modeling

Preservation risk modeling results were compared with the 90th percentile values of modeled values for the 2008–2024 time period; the 90th percentile risk value is 2.72 for Lake Powell and 2.24 for Lake Mead (see **Figure TA 11-1** in **TA 11**, Cultural Resources; Caster et al. 2026).

For both Lake Powell and Lake Mead, the median maximum preservation risk would be lowest in the Wet Flow Category (16.0-31.11 maf) under the CCS Comparative Baseline, No Action Alternative, and all action alternatives at just above 2.0 for Lake Powell and around 2.0 for Lake Mead.

In the Average Flow Category (12.0-14.0 maf), the No Action, Basic Coordination, and Supply Driven Alternatives, as well as the CCS Comparative Baseline, all would have a median risk level at the 2.72 threshold for Lake Powell. However, the No Action Alternative would have the greatest variation in risk in the interquartile range. The median preservation risk for the Enhanced Coordination Alternative site would be about 2.5 and for the Maximum Operational Flexibility Alternative would be just under 2.72; both would have similar interquartile ranges. For Lake Mead in the Average Flow Category, the median risk value would be highest under the No Action Alternative at about 2.4. The Basic Coordination and Enhanced Coordination Alternatives and the CSS Comparative Baseline would have median risk values at or above 2.24, with the interquartile range for the Enhanced Coordination Alternative dropping the most below the 2.24 value. The median for the Maximum Operational Flexibility Alternative would be just below the 2.24 value. The median risk value for the Supply Driven Alternative would be the lowest at 2.0.

In the Critically Dry Flow Category (4.46–10.0 maf), the No Action Alternative would have the median highest preservation risk for Lake Powell at well over 3.5, followed by the CCS Comparative Baseline, the Basic Coordination Alternative, and the Supply Driven Alternative at or just below 3.5. Both the Maximum Operational Flexibility and Enhanced Coordination Alternatives would have an interquartile range that extends down to 2.72; however, the Maximum Operational Flexibility Alternative would have a higher mean risk value above 3.0, while the Enhanced Coordination Alternative would have a lowest mean risk value below 3.0. The median preservation risk model values for Lake Mead in the Critically Dry Flow Category under all scenarios except the No Action Alternative and the CCS Comparative Baseline would be just above the 2.24 value; however, the interquartile ranges for the Basic Coordination and the Supply Driven Alternatives would be much greater than those of the Enhanced Coordination and Maximum Operational Flexibility Alternatives.

Figure TA 11-2 and **Figure TA 11-3** in **TA 11**, Cultural Resources, show the percentage of futures that the preservation risk is below 2.72 for Lake Powell and 2.24 for Lake Mead in at least 90 percent of months. The 2.72 and 2.24 preservation risk values represent the 90th percentile of modeled historical values during 2008–2024, which aligns with the current operational guidelines and includes the period of significant reservoir storage loss.

For Lake Powell, over the full modeling period the Enhanced Coordination Alternative would be the most robust, meeting the 2.72 risk threshold in 58 percent of futures. The Maximum Operational Flexibility Alternative would be less robust, meeting the 2.72 threshold in 36 percent of futures, followed by the No Action Alternative at 23 percent. This pattern is consistent if the modeling period is broken out, with the Enhanced Coordination Alternative performing best in the 2040–2049 time frame at 74 percent.

For Lake Mead, the Supply Driven Alternative would be the most robust by meeting the 2.24 risk threshold in 43 percent of futures. The Maximum Operational Flexibility Alternative would meet the threshold in 37 percent of futures, followed by the Enhanced Coordination Alternative at 26 percent and the Basic Coordination Alternative at 22 percent. If the modeling period is broken out, the Supply Driven Alternative would meet the threshold for 67 percent of futures in the 2040–2049 period and 65 percent of futures in the 2050–2060 time period. The Maximum Operational Flexibility Alternative would meet the threshold of 64 percent and 63 percent of futures for these periods.

Overall, the Enhanced Coordination Alternative would be the most robust for Lake Powell, followed by the Maximum Operational Flexibility Alternative, while the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be the most robust for Lake Mead, followed by the Maximum Operational Flexibility Alternative.

River Flows

Archaeological sites that may be physically affected by changes in river flow are those along the river with the primary impact being from erosion caused by moving water. Built environment resources and specially designated cultural resources that may be most affected by river flow changes are those immediately along the river corridor; however, the latter along the river tend to be more resilient to changes in river flow because they were designed to avoid impacts from shifts in conditions. As with the Lake Powell and Lake Mead datasets discussed above, variable survey coverage and older locational data must be taken into account. To identify the number of archaeological sites, built environment resources, and specially designated cultural resources that may be affected by changes in flow, sites with all or portions of their boundaries in the river corridor (bank to bank) or within 20 meters (66 feet) of the river corridor were sorted out of the overall dataset using a GIS. For additional information on the cultural resources identified along the river by reach, please reference **Figures TA 11-17** and **TA 11-18** in **TA 11**, Cultural Resources.

For all reaches, the primary impacts would include water erosion from river currents during higher releases and flows but may also include exposure from lower water levels where either dam release or flow volumes are reduced; however, these impacts are only considered in this analysis when volumes fall outside the parameters of past releases or flows.

Glen Canyon Dam to Lake Mead

This section summarizes the potential for cultural resources to be affected by river flows below Glen Canyon Dam. Since 2008, after the implementation of the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Interim Guidelines), releases from Glen Canyon Dam have been in the range of around 7.0 maf to around 13.9 maf, averaging around 8.8 maf (see **Section TA 3.1.3**, Lake Powell and Glen Canyon Dam, in **TA 3**, Hydrologic Resources). In general, where annual releases from Glen Canyon Dam deviate from this past range of 7.0–13.9 maf, there is greater potential for impacts on known cultural resources within 20 meters (66 feet) of the river as well as on undiscovered resources that may be present along the river corridor. For additional information on the releases referenced in this analysis, please see **Table TA 3-14** and **Figure TA 3-21** in **TA 3**, Hydrologic Resources.

River flows from Lake Powell to Lake Mead primarily consist of controlled releases from Glen Canyon Dam. WY releases from the dam in the Wet Flow Category (16–31.1 maf) and Average Flow Category (12.0–14.0 maf) would generally fall within the range of past annual release volumes for all modeled scenarios, including the CCS Comparative Baseline, with median WY volumes around or just above 8.0 maf. Neither the CCS Comparative Baseline nor the No Action Alternative and action alternatives would have median volumes that dip below 9.0 maf in the Wet Flow Category, and none would drop below 7.8 maf in the Average Flow Category. Therefore, there would be no additional impacts because none of the modeled scenarios would deviate from the established range. This is also true for the three built environment resources found along this reach, including the boundary of the Lee's Ferry and Lonely Dell Historic District, which extends into the river channel. In the Average Flow Category, the interquartile range for the Enhanced Coordination Alternative would be the only modeled scenario that deviates from the range of past release volumes (7.0 maf up to 13.9 maf), as it is forecasted to potentially drop to around 6.8 maf (25th percentile). Reductions in the volume of WY releases would affect river flows, thereby potentially exposing the Spencer Steamboat. The same drops in river flows, resulting from reduced WY releases from Glen Canyon Dam, would not be detrimental to the three known historic properties within 20 meters (66 feet) of the river.

In the Critically Dry Flow Category (4.46-10.0 maf), median WY release volumes for the CCS Comparative Baseline, No Action Alternative, and all action alternatives would fall below 7.0 maf, to as low as around 5.1 maf under the Enhanced Coordination Alternative. Under the critically dry hydrologic conditions, the CCS Comparative Baseline and the No Action Alternative would perform better than the others relative to the upper limits of their interquartile ranges (75th percentile), which are around 7.5 maf for the CCS Comparative Baseline and 8.2 maf for the No Action Alternative. All of the modeled scenarios could impact the Spenser Steamboat if the reduced volumes of these WY releases cause the river to drop below previous water levels. On the other hand, these same potential drops in river water level would protect the three NRHP-listed or -eligible properties within 20 meters (66 feet) of the river, as previously discussed.

Hoover Dam to Davis Dam

This section summarizes the potential for cultural resources to be affected by river flows below Hoover Dam to Davis Dam. Since 2008, releases from Hoover Dam have been in the range of around 8.5 maf to around 9.6 maf, averaging around 9.2 maf (see **Section TA 3.1.7**, Hoover Dam to Lake Mohave, in **TA 3**, Hydrologic Resources). In general, where annual releases from Hoover Dam deviate from this past range of 8.5–9.6 maf, there is greater potential for impacts on known cultural resources within 20 meters (66 feet) of the river as well on undiscovered resources that may be present along the river corridor. For additional information on the releases referenced in this analysis, please see **Table TA 3-20** and **Figure TA 3-27** in **TA 3**, Hydrologic Resources.

Median annual flow volume in the Wet Flow Category (16.0-31.11 maf) would remain within the range of past annual flow volumes except under the Supply Driven Alternative. Under this alternative, the median annual flows would exceed 9.6 maf by up to 1.0 maf, with the LB Priority approach at 10.4 maf and the LB Pro Rata approach at 10.6 maf. Exceeding the range of past annual flow volumes (that is, being above 9.6 maf) would risk impacting at least 258 archaeological sites within 20 meters (66 feet) of the river that have not been previously affected by river flows if river water levels also rise in this reach. Depending on the river levels, the substructure of the one NRHP-listed built environment resource (Willow Beach Gaging Station) identified within this reach could be affected, but this structure was designed to accommodate historical river flows and was built directly above the river's surface; therefore, impacts are unlikely even under the wet hydrologic conditions presented under the different modeled scenarios.

In the Average Flow Category (12.0-14.0 maf), the CCS Comparative Baseline and the No Action Alternative are the only two modeled scenarios under which median annual flow volumes would remain within the 8.5–9.6 maf range representing previous annual flow volumes below Hoover Dam in this reach, with around 8.5 maf under the CCS Comparative Baseline and 8.7 maf under the No Action Alternative. The action alternatives would not perform as well, with the median annual volume for the Basic Coordination Alternative in the Average Flow Category around 8.1 maf, followed by the Maximum Operational Flexibility Alternative at 7.8 maf, the Supply Driven Alternative (LB Priority approach) also at 7.8 maf, the Supply Driven Alternative (LB Pro Rata approach) at 7.7 maf, and the Enhanced Coordination Alternative at 7.7 maf. Reductions in annual flow volumes could impact archaeological sites where the result is lower water levels along the river. The same drops in river water levels, resulting from reduced annual flow volumes below Hoover Dam, would not be detrimental to NRHP-listed Willow Beach Gaging Station.

In the Critically Dry Flow Category (4.46–10.0 maf), median annual flow volumes would be well below previous volume ranges under the CCS Comparative Baseline, No Action Alternative, and all action alternatives. Under these scenarios, the median annual flow volumes would fall below 8.0 maf, down to as low as around 6.6 maf for the Enhanced Coordination and Maximum Operational Flexibility Alternatives. All of the modeled scenarios could impact archaeological sites if the reduced annual flow volumes cause the river to drop below previous water levels. These same potential drops in river water level would not impact the NRHP-listed Willow Beach Gaging Station.

Within this reach is Lake Mohave, which is operated under a rule curve that maintains end-of-month target elevations between 630 feet and around 646 feet and which has been kept relatively constant at around 641 feet since 2008 (see **Section TA 3.1.7**, Hoover Dam to Lake Mohave, in **TA 3**, Hydrologic Resources). There are no anticipated impacts on any known cultural resources around the reservoir in this portion of the reach, regardless of scenario, because Lake Mohave would continue to be operated under the existing rule curve.

Below Davis Dam

No impacts under the CCS Comparative Baseline, No Action Alternative, and all action alternatives are expected below Davis Dam. Davis and Parker Dams will continue to be operated under the current rule curves that determines end-of-month target elevations for Lake Havasu (see **Section TA 3.1.8**, Davis Dam to Lake Havasu, in **TA 3**, Hydrologic Resources). Imperial Dam is operated to maintain a nearly constant elevation to meet water delivery requirements for major diversions to California and Arizona (see **Section TA 3.1.10**, Cibola Gage to Imperial Dam, in **TA 3**). Additionally, the river below Imperial Dam is characterized by several stretches of mechanically channelized river corridor.

Issue 2: How will changes in dam operations affect sediment availability for aeolian transport to protect archaeological sites in the Grand Canyon?

This section references **Section TA 11.2.3**, Issue 2, in **TA 11**, Cultural Resources, as well as **Section TA 9.2.2**, Issue 1, in **TA 9**, Vegetation Including Special Status Species, and **Section TA 5.2.5**, Issue 4, in **TA 5**, Geomorphology and Sediment. As discussed in S**ection TA 11.2.1**, Methodology, in **TA 11**, the aeolian transport model looks at favorable conditions for wind-borne sand to be present to protect archaeological sites over long periods of time using projected vegetation cover and exposed sand area or sandbar volume (Butterfield and Palmquist 2026; Kelley et al. 2026; Salter and Grams 2026). The vegetation and sandbar volume modeling used is from the Marble Canyon sub-reach from Lee's Ferry to the Little Colorado River. The exposed sand modeling was conducted for the portion of the river from Lee's Ferry to Bright Angel Creek. The general conclusions are pertinent to the entire river.

Overall, less vegetation is better for aeolian sand transport because it leaves sand exposed to be picked up by the wind. As discussed in **Section TA 9.2.2**, Issue 1, and seen in **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species, for all modeled scenarios in wet and moderately wet conditions there would be less vegetation cover (below observed conditions) from higher water levels and longer HFEs. As conditions grow drier, water flows diminish, and HFEs are shorter, vegetation cover increases (see **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). In dry and critically dry conditions, vegetation cover increases and differentiation between alternatives can be seen. In the Critically Dry Flow Category (4.46–10.0 maf), the No Action Alternative would have the highest level of vegetation cover (with median acreage just under 30 acres), followed by the Supply Driven Alternative (with median acreage just under 25 acres). The Basic Coordination, Enhanced Coordination, and Maximum Operational Flexibility Alternatives would have the least median acreage of vegetation cover in the Critically Dry Flow Category, at about 20 acres.

Increased sandbar volume means more sand is available to protect archaeological sites. In general, as conditions get drier and the amount of water flowing through the river decreases, sandbar volume increases. As discussed in **Section TA 5.2.5**, Issue 4: Sandbar Volume, and shown in **Figure TA 5-**

12 in **TA 5**, Geomorphology and Sediment, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would outperform the other scenarios in sandbar volume increase, with a value at or above a median of 1,700 cubic meters for the Average Flow Category (12.0–14.0 maf) through the Critically Dry Flow Category (4.46–10.0 maf). The Basic Coordination and Supply Driven Alternatives would perform similarly in the Average Flow Category but would then drop in sandbar volume as conditions become drier.

The results of the WY average of exposed sand area modeling are seen in **Figure TA 11-4** in **TA 11**, Cultural Resources. As with sandbar volume, increased sand area is beneficial for the aeolian transport of sand to protect archaeological sites. In the Average Flow Category (12.0–14.0 maf), exposed sand area is at or just below the historical median acreage. As conditions become drier, all the modeled scenarios perform similarly with forecasted median exposed sand area above the observed median, with the Enhanced Coordination Alternative having a slighter higher median than the other action alternatives.

The above three models are used in the aeolian sand model. **Figure TA 11-5** in **TA 11**, Cultural Resources, shows the results of the aeolian sand modeling, in which some futures meet one of two criteria: either the annual sand volume is greater than the median observed sand volume over the last 20 years and the vegetation cover area is less than then median observed area over the last 20 years or the sandbar volume is greater than 1.5 times the initial condition. Based on previous studies and as shown in the table (in the highlighted row), those criteria being met at least 1 out of every 3 years is the optimal condition for enough sand to be available for aeolian transport.

Over the full modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would be the most robust at meeting the desired conditions (the criteria being met at least 1 out of every 3 years) in 15 percent of futures. They are followed by the No Action Alternative, in which the desired conditions would be met in only 11 percent of futures. The Supply Driven Alternative would be the least robust, meeting the desired conditions in only 2 percent of futures. If the year interval is lengthened to 1 out of 4, 5, or 6 years, the models perform in a similar overall pattern, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives still performing the best.

Summary Comparison of Alternatives

The Enhanced Coordination and Maximum Operational Flexibility Alternatives would perform better for Lake Powell in terms of maintaining water levels that would protect submerged resources. They would also have the two most robust performances with respect to preservation risk. Because the continual inundation of archaeological sites is more conducive to preservation than repeating cycles of inundation and exposure and risks of wave action, changes in lake elevations that may expose previously inundated resources to impacts such as wet/dry cycling and wave action are the biggest concern. As conditions become drier at Lake Powell, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would perform the best in the Average Flow Category (12.0-14.0 maf) with median water elevations at or above 3,620 feet. They also would perform best in the Critically Dry Flow Category (4.46–10.0 maf); however, the projected medians would still be below 3,580 feet, which would expose at least 274 sites and any undiscovered sites at these elevations. The Enhanced Coordination and Maximum Operational Flexibility Alternatives would also be the most robust with respect to aeolian transport in the Grand Canyon. Both alternatives would meet the desired conditions at least 1 out of every 3 years in 15 percent of futures.

For Lake Mead, however, the Supply Driven Alternative would perform the best in the Average Flow Category (12.0–14.0 maf), followed by the Enhanced Coordination and Maximum Operational Flexibility Alternatives. Projections indicate that the Supply Driven Alternative would have median elevations up to 1,150 feet, while the Enhanced Coordination and Maximum Operational Flexibility Alternatives would have median elevations around 1,100 feet. In the Critically Dry Flow Category (4.46–10.0 maf), all scenarios would result in the exposure of all 240 sites in the Lake Mead dataset as well as any undiscovered sites at elevations at or below 950 feet; however, the Supply Driven Alternative would have the potential to protect more sites with upper interquartile ranges at about 1,120 feet. In addition, the Supply Driven Alternative would be the most robust for Lake Mead with respect to preservation risk, with 43 percent of the modeled futures over the full modeling period meeting the 2.42 threshold, followed by the Maximum Operational Flexibility Alternative with 37 percent of futures.

Complicating these conclusions are modeling results showing that, in the reaches between Glen Canyon Dam and Lake Mead and Hoover Dam to Lake Mohave, the median volume drop would be lower under the Enhanced Coordination Alternative and Maximum Operation Flexibility Alternative in the Critically Dry Flow Category (4.46–10.0 maf) than under the other alternatives. Under all of the modeled scenarios, the Spenser Steamboat could be impacted if the reduced volumes of these WY releases cause the river to drop below previously observed water levels. On the other hand, these same potential drops in river water level may provide some protection from river currents for resources within 20 meters (66 feet) of the river.

Below Davis Dam, few to no impacts (regardless of flow category) are expected because the dams below Lake Mohave are operated under guidelines that maintain lake elevations or target water deliveries, and there are several stretches of channelized banks.

3.12 Paleontological Resources

3.12.1 Affected Environment

Overview and Study Area

This section summarizes the paleontological resource environment of Lake Powell, Lake Mead, and the lower Colorado River corridor. The full detailed analysis of the paleontological resources' affected environment can be reviewed in **TA 12**, Paleontological Resources. Paleontological resources include (with some exceptions) any fossilized remains, traces, or imprints of organisms preserved in or on the earth's crust. The Paleontological Resources Preservation Act of 2009 (PRPA; 16 USC 470aaa–470aaa-11) and its implementation rule (43 CFR 49) require Department agencies to preserve, manage, and protect paleontological resources on lands administered by Reclamation, the NPS, the BLM, and the FWS and ensure these federally owned resources are available for current and future generations to enjoy and study as part of America's national heritage.

The study area for paleontological resources stretches from the northern extent of Lake Powell to the SIB in California via the Colorado River. It covers approximately 3 million acres across Utah, Arizona, Nevada, and California. This area includes known and unknown resources in Lake Powell and Lake Mead.

It is important to note that the resources in the operational zones are vulnerable to the effects from wave action and other disturbances, and those above the fluctuating pool elevation are at risk for damage and disturbance by visitation. The PRPA requires federal protection, but the ongoing exposure of these resources highlights the need for more effective preservation efforts. The PRPA also requires Department agencies to develop plans for inventory and monitoring using scientific principles and expertise. These plans must emphasize interagency coordination and collaborative efforts, when possible.

Potential Fossil Yield Classification System

The study area was mapped using the BLM's Potential Fossil Yield Classification (PFYC) system. This system assigns ranks to geologic units based on the relative abundance of vertebrate or other fossils and the sensitivity of those fossils to adverse impacts. For more information on how the PFYC system was created and is regularly updated, please refer to **Section TA 12.1.1**, Study Area, in **TA 12**, Paleontological Resources. **Table 3-8**, below, depicts the acreages of PFYC ranks within the study area. Geologic units with a higher potential for containing paleontological resources are assigned a higher number. Approximately 27 percent of the study area is mapped as having a high or very high occurrence of paleontological resources. Maps of the study area can be found in **Section TA 12.1.1** (**Map TA 12-1** through **Map TA 12-9**).

Table 3-8
Acres of PFYC Classes in the Study Area

PFYC Class	Total Acres
1 (very low)	433,209
2 (low)	353,109
3 (moderate)	543,355
4 (high)	713,409
5 (very high)	103,828
U (unknown)	525,265
W (water)	383,946
Total acres	**3,056,121***

Source: BLM GIS 2025.
*PFYC data do not cover the entire study area, especially in the waterbodies and portions of the Colorado River.

Key Drivers and Trends

Fluctuating water levels in both Lake Mead and Lake Powell pose significant threats to paleontological resources, including fossils and trackways preserved in sedimentary rocks. In reservoirs, cycles of inundation and exposure weaken softer rocks, such as sandstone, making them more susceptible to erosion. As water levels recede, previously submerged fossils are exposed to environmental factors like wind, sun, and temperature changes, which accelerate degradation. While sediment deposition can temporarily protect some sites, the exposure of fossil-rich layers as water levels recede increases the likelihood of weathering, fragmentation, and disturbance from human activity.

Human activity further exacerbates these challenges because exposed fossil sites attract recreational use, leading to soil compaction, vegetation damage, and unauthorized fossil collection. Water-related impacts, such as flooding, controlled reservoir releases, and increased river erosion, also threaten fossil preservation by accelerating the removal of fossil-bearing sediments. While erosion can reveal new paleontological resources, it simultaneously increases the risk of their loss. The study area, characterized by a steep topography and high recreational use, faces elevated erosion rates, making the balance between discovery and preservation increasingly challenging.

Erosion is the primary agent that exposes paleontological resources on the surface to then await discovery and documentation. Lake Powell and Lake Mead are interconnected; adjustments of water releases at Lake Powell have a downstream effect on Lake Mead. The impacts on paleontological resources due to natural processes are the same at both reservoirs, but the intensity at which they occur and on what resources they occur vary. Paleontological resources in Glen Canyon NRA are largely more understood and considered to be highly scientifically important. Most of the area is ranked PFYC 4 (high) or PFYC 5 (very high), including the shorelines (BLM GIS 2025). In Lake Mead NRA, the paleontological resources are less understood, and much of the shoreline is mapped as PFYC U (unknown; BLM GIS 2025). Therefore, the erosion concerns at Lake Powell are extremely high, as these conditions are affecting geologic units with high and very high paleontological value.

Reservoirs and Colorado River Corridor Overview

Lake Powell and Glen Canyon Dam

Lake Powell and Glen Canyon Dam make up Glen Canyon NRA, which spans southern Utah and northern Arizona and contains one of the most extensive sedimentary records on the Colorado Plateau. This record represents approximately 300 million years of geologic history and chronicles significant events, including the assembly and breakup of Pangea, the evolution of inland seas, and the incision of the Colorado River (Anderson et al. 2010).

Glen Canyon NRA staff is conducting a paleontological resources inventory survey; because of the size of the recreation area, the survey is being done in phases, with the latest phase completed in 2024. The three inventory reports provide the baseline data for a breadth of paleontological resources found within Glen Canyon NRA. Despite these efforts, natural processes such as erosion, mass wasting, and fluctuating water levels continue to expose and degrade fossil-bearing strata. Additionally, impacts from human intervention, such as reservoir sedimentation, vandalism, and unauthorized fossil collection, pose ongoing threats to resource preservation (Graham 2016; Santucci et al. 2009). In some areas, the buildup of sediment from dam operations may enhance fossil preservation by burial, while in others, it prevents discovery of those fossils. For more information about the paleontological resources in Glen Canyon NRA, please reference **Section TA 12.1.1**, Study Area.

Lake Mead and Hoover Dam

Lake Mead NRA covers 1.5 million acres of southeastern Nevada and northwestern Arizona. Lake Mead NRA showcases a stratigraphic record spanning more than 500 million years of geologic history, documenting the evolution of the southwestern margin of North America. The NPS completed a comprehensive paleontological resource inventory in 2018. This inventory established baseline data for fossil-bearing formations and identified areas with high fossil potential; the inventory is confidential.

Resources at Lake Mead NRA are vulnerable to the same natural processes and human impacts described at Glen Canyon NRA. Continued monitoring and research are recommended to protect resources at Lake Mead NRA.

Lower Colorado River Corridor

Reclamation completed a paleontological resource inventory for the lower Colorado River region in 2020, which contained the river corridor as it extends from southern Nevada to the Mexico border (Bonde and Slaughter 2020). The corridor contains a sedimentary geologic record spanning 500 million years. Although not fully continuous, the corridor includes units representative of most geologic periods.

Under current conditions, water-related impacts such as erosion and recreation threaten the preservation of paleontological resources in the lower Colorado River corridor. Flooding events and controlled releases of reservoir waters can submerge fossils or increase river velocity and erosion, consequently displacing fossils from their geologic units. Water systems with steep cliffs and undercutting are also subject to higher rates of erosion and potential resource loss than flatter areas. Water-based recreational opportunities may unintentionally invite theft, vandalism, or indirect disturbance to fossils.

3.12.2 Environmental Consequences

This section provides a summary of the potential impacts on paleontological resources for the No Action Alternative, four action alternatives, and CCS Comparative Baseline. Refer to **Section TA 12.2**, Environmental Consequences, for more details regarding the analysis of impacts.

Methodology

In this section, impacts on paleontological resources include those resulting from Reclamation’s management of the water in Lake Powell and Lake Mead. Two types of analyses are used to evaluate impacts: preservation risk modeling, developed by the USGS and NPS, and aeolian transport-vegetative cover-HFE joint modeling, also developed by the USGS (Caster et al. 2026; Kelley et al. 2026). Additionally, PFYC data were used to analyze areas of high fossiliferous potential within the impact analysis area, and CRSS modeling of reservoir elevations was used to determine exposure risks.

The paleontological preservation risk rank model is informed by PFYC data and natural preservation hazards (slope erosivity, fetch distance, and water fluctuations) (Caster et al. 2026). To analyze this model using the DMDU framework, the model summarizes 10-foot elevation bins in Lake Powell and 5-foot elevation bins in Lake Mead so that each elevation from full pool to empty has a preservation risk rank. Next, projected monthly lake elevations are related to those elevation bins to estimate the preservation risk rank. As lake elevations drop, preservation risk generally increases. The model assumes that all resources have value and high erosion potential, and dense resources represent the highest risk; those with low erosion potential and no predicted resources represent the lowest risk.

Impact Analysis Area

The impact analysis area for paleontological resources consists of the Colorado River corridor from the upper limits of Lake Powell in Utah, through the Grand Canyon and Lake Mead in Arizona, and from Hoover Dam to the SIB.

Assumptions

The paleontological resource results are direct outputs from the Preservation Risk Model and Joint Model. The impact analysis area includes known, unknown, and predicted resources and does not identify specific localities.

Impact Indicators

Four impact indicators were used to assess the impacts on paleontological resources due to operational activities: end-of-year lake elevations, changes in river flows, paleontological preservation risk rank, and the increase or decrease in sandbar building and the availability of windblown sediments to protect exposed resources.

Issue 1: How would fluctuations in water levels due to changes in dam operations (primarily in Lake Powell and Lake Mead) impact the exposure, erosion, and degradation of paleontological resources, including fossils and trackways?

For a detailed analysis of how the alternatives and CCS Comparative Baseline influence the preservation risk rank and impact the exposure, erosion, and degradation of paleontological resources, please reference **Section TA 12.2.5**, Issue 1.

This analysis references the modeling of paleontological preservation risk at the reservoirs. The model defines a historically derived threshold that is the 90th percentile risk rank from 2004 to 2008 during the LTEMP's development. Exceeding this value means that a larger percentage of potential resources are exposed to erosion risks than what has happened since the reservoirs were filled. The threshold at Lake Powell is a preservation risk rank of 2.93. The threshold at Lake Mead is 2.33.

Lake Powell

Reference **Tables TA 12-3** and **Figures TA 12-4**, **12-5**, and **12-6** for the full modeling results of the preservation risk at Lake Powell. As shown in **Figure TA 12-4**, the Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative have similar ranges that are around or below the threshold in the Average Flow Category (12.0–14.0 maf). However, the Enhanced Coordination Alternative has a median risk value that is approximately 14 percent lower than what is modeled for the Maximum Operational Flexibility Alternative (2.45 and 2.85, respectively). In the Dry Flow Category (10.0–12.0 maf), the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative perform similarly well, although all alternatives exceed the historically derived threshold under the Critically Dry Flow Category (4.46–10.0 maf).

Focusing on trends in the drier hydrologic conditions, the Supply Driven Alternative performs similarly to the CCS Comparative Baseline; the medians and ranges are above the threshold in the dry and critically dry flow categories, although the Supply Driven Alternative exhibits slightly less variability. The No Action and Basic Coordination Alternatives also perform similarly, with medians higher than those of the Supply Driven Alternative and CCS Comparative Baseline.

When looking across the full modeling period (which includes the full range of potential hydrologic futures), the Enhanced Coordination Alternative is the most robust at achieving a risk rank of 2.9 in 90 percent of months over the full modeling period, doing so in 47 percent of the futures (**Figure TA 12-5**). The Basic Coordination and No Action Alternatives perform similarly to the CCS Comparative Baseline, succeeding in 18 percent, 22 percent, and 19 percent of futures, respectively. The Maximum Operational Flexibility Alternative succeeds 28 percent of the time over the full modeling period, which is just similar enough to the CCS Comparative Baseline and No Action Alternative. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the least robust over the full modeling period at 13 percent of successful futures.

These trends are supported by the vulnerability analysis (**Figure TA 12-6**), which looks at flow conditions that could cause the preservation risk rank to exceed the threshold. The Enhanced Coordination Alternative results in undesirable performance when the 10-year average flow is below 11.1 maf. Approximately 75 percent of the reference hydrology traces include averages this low or lower. As a historical reference, the driest observed 10-year average for the Lees Ferry flow was 11.8 maf and occurred from 2012 to 2021. The CCS Comparative Baseline and Basic Coordination Alternative perform similarly to each other, with paleontological resources becoming vulnerable at approximately 12.1 and 12.3 maf, respectively. More than 75 percent of the reference hydrologic traces include average flows this low or lower. The No Action Alternative and Maximum Operational Flexibility Alternative perform similarly to the driest 10-year average flow from 2012 to 2021 (11.9 maf, 11.7 maf, and 11.8 maf, respectively). Under both alternatives, paleontological resources are vulnerable to conditions that are close to what has already occurred.

Lake Mead

Reference **Table 12-4** and **Figures TA 12-7**, **12-8**, and **12-9** for the full modeling results of the preservation risk at Lake Mead. As shown in **Figure TA 12-7**, the Supply Driven Alternative and the Maximum Operational Flexibility Alternative perform almost identically in the Average Flow Category (12.0–14.0 maf), with similar median preservation risk ranks and an interquartile range at or below the 2008–2024 defined threshold. The Enhanced Coordination Alternative has a large median preservation risk, but it has a similar interquartile range to the other best-performing alternatives. The Basic Coordination Alternative performs similarly to the Enhanced Coordination Alternative, but it has greater variability and a larger proportion of its interquartile range above the historically defined threshold. Under drier conditions, the Supply Driven Alternative and Basic Coordination Alternative perform similarly, with medians at or just above the threshold (2.3) and similar interquartile ranges. The Enhanced Coordination Alternative has the smallest interquartile range, but it has the highest median value above the threshold in the Critically Dry Flow Category (4.46–10.0 maf). The No Action Alternative has more than 50 percent of the values above the threshold and a large interquartile range.

When looking across the full modeling period, the Supply Driven Alternative was the most robust at achieving a risk rank of 2.3 in 90 percent of months, doing so in 35 percent of futures. The Maximum Operational Flexibility Alternative performs similarly to the Supply Driven Alternative, achieving a risk rank of 2.3 in 29 percent of futures. The No Action Alternative and CCS Comparative Baseline are the least robust and perform identically, succeeding in 6 percent of futures; the Basic Coordination Alternative and the Enhanced Coordination Alternative perform similarly (15 percent and 18 percent successful futures).

These trends are supported by the vulnerability analysis (**Figure TA 12-9**). Paleontological resources are the most vulnerable to risk under the CCS Comparative Baseline and the No Action Alternative. Undesirable performance occurs at 13.5 maf; nearly 100 percent of the reference hydrologic traces include average flows of 13.5 maf or lower. These two scenarios are vulnerable to conditions that have already occurred; the 20-year average flow at Lees Ferry from 2002 to 2021 was 13.1 maf. The Basic Coordination Alternative and the Enhanced Coordination Alternative are vulnerable to increased risk to paleontological sites at flows of 13.0 and 12.9 maf, respectively. The Maximum Operational Flexibility Alternative results in undesirable performance if the future includes a 20-year average flow of 12.5 maf, which is the same as the 2002–2021 observed driest flow. Under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), paleontological resources become vulnerable to risk at flows of 12.4 maf. Approximately 75 percent of reference hydrologic traces are drier than 12.4 maf.

Issue 2: How would altered sediment transport, including both fluvial and aeolian deposition patterns, affect the preservation and stability of paleontological resources?

The preservation and stability of paleontological resources along the Colorado River corridor are closely tied to sediment dynamics, particularly the deposition and redistribution of fine sediments through fluvial and aeolian processes. Sediment burial helps protect surface-exposed resources from erosion, weathering, and human disturbance, while changes in the magnitude or timing of sediment delivery may either enhance or degrade preservation conditions. However, increased exposure of sandbars and sediment surfaces typically heightens the risk of erosion, weathering, and loss of fossil integrity, while sediment deposition and rapid burial may provide temporary protection from degradation. Frequent water level fluctuations that alternately expose and inundate sediments are generally detrimental to long-term preservation.

Fluvial Sediment Transport

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to the fraction of total sand mass transported by sandbar-forming flows. For more information, please reference **TA 5**, Geomorphology and Sediment.

As shown in **Figure TA 12-10** in **TA 12**, Paleontological Resources, the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform the same. Both alternatives are the most robust at achieving sandbar-building conditions, doing so in 82 percent of futures. The Supply Driven Alternative and the Basic Coordination Alternative are similarly robust (77 percent and 74 percent of futures, respectively). Sandbar-building conditions indirectly result in the preservation and stabilization of paleontological resources present in and around the sandbars. Fossils are buried during sediment transport and protected from erosion and other types of degradation in the fluvial channel. In contrast, the No Action Alternative was successful in only 49 percent of futures; the CCS Comparative Baseline produced 39 percent of successful futures. Under the No Action Alternative, fossils and other paleontological resources would be indirectly affected by sandbar erosion between HFEs and not effectively reburied during sandbar-building events.

Aeolian Sediment Transport

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to favorable conditions for wind-born sand to be present to protect paleontological resources over long periods of time. The model incorporates the vegetation, sandbar volume, and exposed sand area modeling. For more details, please reference **Section TA 12.2.1**, Methodology.

Figure TA 12-12 in **TA 12**, Paleontological Resources, shows the results of the aeolian sand modeling, in which the percentage of futures meet one of two criteria: Either the annual sand volume is greater than the median observed sand volume over the last 20 years and the vegetation cover area is less than the median observed area over the last 20 years, or the sandbar volume is greater than 1.5 times the initial condition. The highlighted row shows when those conditions are met at least 1 out of every 3 years, which is the optimal time frame for enough sand to be available for aeolian transport based on previous studies.

Over the full modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust; they meet the desired conditions of at least 1 out of every 3 years in 15 percent of futures, followed by the No Action Alternative, which meets the desired conditions only in 11 percent of futures. The Supply Drive Alternative is the least robust, meeting the desired conditions in only 2 percent of futures. If the year interval is lengthened (that is, to 1 out of 4, 5, or 6 years), the models perform in a similar overall pattern, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives performing the best.

When results are split out over intervals from 2027–2039, 2040–2049, and 2050–2060, the percentage of futures meeting the desired conditions increase for both the Enhanced Coordination and the Maximum Operational Flexibility Alternatives from 27 percent to 53 percent and 51 percent and from 25 percent to 55 percent and 54 percent, respectively. These results seem to indicate an increase in acceptability over time, which may correlate to increased available sand over time; however, the perceived increase is driven by an increase in sandbar volume over time in the modeling with the understanding that HFEs would continue as planned. In reality, the decision to conduct HFEs depends on the annual review.

Issue 3: How would adjustments to dam operations and water levels alter human access to newly exposed fossil sites, and what are the potential risks of increased disturbance, unauthorized collection, and recreational impacts on paleontological resources?

This section summarizes the potential for paleontological resources to be exposed to increased levels of disturbance, unauthorized collection, and recreational impacts using the hydrologic modeling results for Lake Powell and Lake Mead elevations. This analysis incorporates the analysis of reservoir elevations detailed in **Section TA 3.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources**.** For a detailed analysis of how the alternatives and CCS Comparative Baseline influence the risk of human disturbance to paleontological resources, please reference **Section TA 12.2.7**, Issue 3.

Lake Powell

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to increased disturbance at, unauthorized collection of, and recreational impacts on paleontological resources at Lake Powell. For a more detailed analysis of recreation at Lake Powell, please refer to **TA 14**, Recreation.

As shown in **Figure TA 3-7** in **TA 3**, Hydrologic Resources, the alternatives perform similarly with respect to maintaining lake elevations and achieving desirable paleontological preservation risk ranks. The Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative are the most robust at staying above a 3,500-foot elevation in 100 percent of months over the full modeling period, doing so in 87 percent and 82 percent of futures, respectively. These results are similar to the robustness of both alternatives with regard to achieving the historically derived preservation risk threshold in 90 percent of months.

The No Action Alternative is the least robust at maintaining a 3,500-foot elevation in 100 percent of months, doing so in 20 percent of futures over the full modeling period. The No Action Alternative is only 71–80 percent robust at maintaining this elevation in 60 percent of months. The CCS Comparative Baseline, Basic Coordination Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) perform similarly, maintaining the 3,500-foot elevation in 100 percent of months in 29 percent, 25 percent, and 24 percent of futures, respectively.

Alternatives that are more robust at maintaining a 3,500-foot elevation at Lake Powell are inherently more robust at inundating paleontological resources below a 3,500-foot elevation. Therefore, the risk of human disturbance would be for resources above 3,500 feet. The preservation risk rank historically derived threshold is achieved at approximately 3,500-foot elevation at Lake Powell. Under the Maximum Operational Flexibility Alternative, elevations at Lake Powell would be most consistently at or above 3,500 feet, which would result in the inundation of the most paleontological resources and the least amount of shoreline expansion for visitors to access resources.

Lake Mead

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to increased disturbance at, unauthorized collection of, and recreational impacts on paleontological resources at Lake Mead.

As shown in **Figure TA 3-12** in **TA 3**, Hydrologic Resources, the alternatives perform similarly with respect to maintaining lake elevations and achieving desirable paleontological preservation risk ranks. The Supply Driven Alternative (LB Pro Rata approach) and Maximum Operational Flexibility Alternative are similarly robust at keeping Lake Mead's elevation above 975 feet in 100 percent of months, doing so in 80 percent and 79 percent of futures, respectively. The Enhanced Coordination Alternative and the Supply Driven Alternative (LB Priority approach) are also similarly robust, maintaining Lake Mead's elevation above 975 feet in 75 percent and 71 percent of futures, respectively.

The No Action Alternative is the least robust, keeping Lake Mead's elevation above 975 feet in 100 percent of months in 25 percent of futures over the full modeling period. The CCS Comparative Baseline's robustness is 45 percent; the Basic Coordination Alternative's robustness is 58 percent.

Summary Comparison of Alternatives

The continual cycle of inundation of paleontological resources is more conducive to preservation than repeated cycles of inundation and exposure and risks of wave action. Changes in lake elevations that may expose previously inundated fossils and other resources are the biggest concern. When lake elevations drop, indirect impacts, such as those from human disturbance and recreational use, can also occur. For Lake Powell, the Enhanced Coordination Alternative performs best with regard to minimizing the preservation risk in all hydrologic conditions, except the Critically Dry Flow Category (4.46–10.0 maf), followed by the Maximum Operational Flexibility Alternative. Both alternatives exhibit median risk ranks that are at or below the threshold.

The Basic Coordination Alternative is the least effective action alternative with regard to meeting the paleontological preservation risk threshold. This alternative becomes successful at the Moderately Wet Flow Category (14.0–16.0 maf), but it consistently exceeds the threshold at the Average Flow Category (12.0–14.0 maf) and drier. The No Action Alternative and CCS Comparative Baseline performed similarly to the Basic Coordination Alternative.

For Lake Mead, the Supply Driven Alternative and the Maximum Operational Flexibility Alternative perform similarly and produce a median preservation risk rank around, or just above, the historically derived threshold in all hydrologic conditions except for the Critically Dry Flow Category (4.46–10.0 maf). All alternatives exceed the historical preservation risk conditions under the Critically Dry Flow Category (4.46–10.0 maf).

Under the Maximum Operational Flexibility Alternative, critical lake elevations would be maintained above 3,500 feet in Lake Powell and 975 feet in Lake Mead in 87 percent and 80 percent of futures, respectively. The operations proposed under the Maximum Operational Flexibility Alternative would result in the least amount of time that paleontological resources below critical elevations are exposed to human disturbance and the associated impacts. The No Action Alternative would be the least robust at both reservoirs.

Under the Maximum Operational Flexibility Alternative, the paleontological preservation risk would be minimized to the greatest extent at both reservoirs. Paleontological resources that are inundated by lake elevations would not be exposed to erosion, degradation, and the repeated cycles of inundation and exposure and wave action. The Enhanced Coordination Alternative would also minimize the paleontological preservation risk in the reservoirs, but it would do so more consistently at Lake Powell than at Lake Mead. Considering the amount of, and scientific importance of, paleontological resources present in Lake Powell, the Enhanced Coordination Alternative would be the most effective at minimizing the risk in this reservoir. The Enhanced Coordination Alternative would also be effective in Lake Mead, but not as effective as the Maximum Operational Flexibility Alternative.

The river corridor, from below Hoover Dam to the SIB, is not well mapped by the PFYC system. Classifications in the corridor are mostly PFYC W (water). While possible, the presence or impacts on scientifically important vertebrate fossils are not anticipated within the river corridor when compared with the potential for known or undiscovered fossils in the reservoirs. The Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative are the most robust alternatives with regard to sediment transport in the river corridor. Sediment transport would indirectly preserve and stabilize the known and unknown fossil localities.

Operations under the Maximum Operational Flexibility Alternative would indirectly create conditions that are most conducive to the preservation of paleontological resources in the analysis area, as indicated by this alternative's comparatively strong performance across the full suite of models.

3.13 Tribal Resources

3.13.1 Affected Environment

The Colorado River, its canyons, and the associated ecosystems figure prominently in the cultural traditions of many tribal communities. For these tribes, the river and canyons are living entities consisting of sacred spaces, the homes of their ancestors, the residence of the spirits of their dead, and the source of culturally important resources. Many tribes see themselves as stewards of the Colorado River and its canyons, which are a vital part of the living and spiritual world. Caring for the river and the canyons is their responsibility. Tribal resources can include archaeological resources, archaeological structures, topographic features, habitats, plants, wildlife, and minerals that Indigenous peoples, tribal nations, or other groups consider essential for the preservation of traditional culture and traditional values. Tribal interests also include values and resources reflected in other sections in this Draft EIS, including water for drinking and agriculture, recreational resources, and many other socioeconomic and environmental aspects that overlap other sections.

The traditional values of living communities can be manifested at locations called TCPs, Indian sacred sites, or cultural landscapes. Many tribes consider the Colorado River and its canyons to be a TCP. As described by NPS guidance on TCPs (NPS 2024b), a TCP is "a building, structure, object, site, or district that may be listed or eligible for listing in the National Register for its significance to a living community because of its association with cultural beliefs, customs, or practices that are rooted in the community's history and that are important in maintaining the community's cultural identity." Of the groups concerned, the Hualapai Tribe (Coulam 2011), Hopi Tribe (Hopi CPO 2001), Navajo Nation (Maldonado 2011), and Pueblo of Zuni (Dongoske 2011) have prepared NRHP nomination forms for the Colorado River and its canyons as a TCP. Reclamation is actively consulting with the tribes regarding the Colorado River and its canyons, including associated traditional ecological knowledge; Reclamation will incorporate that knowledge as it becomes available.

The study area for tribal resources is identical to that discussed in **TA 11**, Cultural Resources, and **TA 18**, Indian Trust Assets. It extends from the northern extent of Lake Powell to the SIB and consists of the Colorado River channel from bank to bank, except from Glen Canyon Dam to Lake

Mead, where it stretches from canyon rim to canyon rim. The study area also includes a 0.5-mile buffer on either side of the riverbank or canyon rim. The study area coincides with the search area used for a Class I records search conducted for this EIS document (Tremblay et al. 2024a, 2024b; Eddy et al. 2024; Winslow et al. 2024; Eskenazi 2024).

The 14 Native American tribes listed here consider portions of the study area to be part of their homelands; the following eight tribes are associated directly with the Grand Canyon: A:shiwi (Zuni), Ndee (Western Apache), Diné (Navajo), Havasupai, Hualapai, Hopi, Nüümü (Southern Paiute), and Yavapai. Five tribes—the Cocopah, Pipa Aha Macav (Mojave), Piipaash (Maricopa), Quechan, and Xalchidom (Halchidhoma)—have homelands along the lower Colorado River where it flows south to the Gulf of California. One group, the Núuchi (Ute), used northeastern portions of the river and study area. Brief ethnographic summaries of these tribes are provided in **Sections TA 13.1.1** through **TA 13.1.13**. These summaries are derived primarily from the multivolume Class I cultural resources literature review conducted in support of this analysis (Tremblay et al. 2024a, 2024b; Eddy et al. 2024; Winslow et al. 2024; Eskenazi et al. 2024).

Several known or documented TCPs within or adjacent to the study area have been listed or are eligible for listing in the NRHP (**Table TA 13-1**). One each is recorded for the A:shiwi and Hopi within Grand Canyon. Sugarloaf Mountain to the west of the lower Colorado River is claimed by the A:shiwi, Diné, Hopi, Hualapai, Nuwuvi, Pipa Aha Macav, and Yavapai. The Ripley Intaglios are considered sacred by all the Yuman Tribes. The Yuman Tribes consider their origin place, Avi Kwa Ame (Spirit Mountain), to be sacred; it is beyond the project study area but within the newly created Avi Kwa Ame National Monument. All tribes revere the Colorado River. The Grand Canyon itself is an NRHP-eligible TCP for multiple tribes. Several important locations within the Grand Canyon TCP have been formally recorded in the canyon for the A:shiwi and Hopi and documented in ethnographic studies for the Diné and Hualapai.

Tribes consider places associated with origin stories, migrations, songs, and ceremonies to be sacred TCPs, as are ancestral sites, trails, cairns, rock writing, petroglyphs, pictographs, and geoglyphs. All water sources, especially those that come from belowground, are sacred. Plants, animals, and minerals are considered traditional cultural resources, often associated with specific locations. Reclamation is in ongoing consultation with tribes to identify specific locations and resources that are important to each tribe.

3.13.2 Environmental Consequences

Methodology

Of primary concern is how the alternatives might affect the integrity and sacredness of tribal resources. Because these resources attain significance through tribal cultural customs, and because many of these resources are sacred and their locations are confidential, the tribes are best situated to understand how the alternatives might affect them. Accordingly, the analysis of impacts is largely a qualitative analysis of issues that is driven by ongoing tribal consultation efforts.

There are many federally recognized tribes with entitlements to or contracts for Colorado River water or who may be affected or have interests in the alternatives. There are 30 federally recognized tribes within the geographic Basin. Reclamation consults regularly with these tribes regarding Colorado River issues. Additionally, the Ten Tribes Partnership is a coalition of 10 federally recognized tribes with rights and unresolved claims to Colorado River water. The partnership was created in 1992 and has an ongoing consultation relationship with Reclamation. Of the 22 federally recognized tribes in Arizona, 14 have fully resolved rights, adjudicated rights, or partially resolved rights to water from the Colorado River. A significant portion of that water is provided through the CAP. Reclamation has a long-standing and ongoing consultation relationship with tribes receiving Colorado River water through the CAP. Reclamation consults not only with tribes who hold water rights or are located within the Basin's geographic boundary but also with a total of 43 tribes who may be affected or have interests in actions on the Colorado River. Consultation and coordination with these tribes are ongoing.

Impact Analysis Area

The study area for tribal resources is identical to that discussed in **TA 11**, Cultural Resources. It includes the Colorado River corridor from the upper limits of Lake Powell in Utah, through the Grand Canyon in Arizona and Lake Mead in Arizona, and from Hoover Dam to the SIB.

Assumptions

The assumption for the analysis is as follows:

- Tribes will provide information regarding specific tribal resources and potential impacts on those resources during consultation.

Impact Indicators

The following are the impact indicators for this analysis:

- Qualitative assessment of potential impacts on TCPs informed by tribal consultation
- Qualitative assessment of potential impacts on culturally important resources informed by tribal consultation and by reference to relevant quantitative analysis sections of the EIS (for example, **TA 9**, Vegetation, and **TA 8**, Biological Resources – Fish and Aquatic Resources)

Issue 1: How would changes in dam operations affect TCPs?

Historic places are principally significant for their association with culturally significant events, as told through Indigenous oral history, or their association with individuals named by those traditions. Impacts on TCPs would consist primarily of changes to the natural environmental context resulting from continued active management of reservoir levels and water releases to downstream river segments. Impacts could also occur as reservoir elevations change and expose TCPs to increased visitation. Because TCPs are a specific category of historic property, adverse impacts on TCPs would be addressed though the project's programmatic agreement developed in compliance with Section 106 of the NHPA or through ongoing consultation with affected tribes.

Exposure of TCPs as lake levels fluctuate as a result of management actions described by the alternatives would facilitate access to these culturally important locations by tribal members; however, exposure would also increase access for non-Native visitation. End-of-year lake elevations for each alternative are explored in detail in **TA 3**, Hydrologic Resources, and are summarized here in the discussion of impacts on TCPs.

Across all alternatives and the CCS Comparative Baseline, Lake Powell's median WY elevations are generally similar under wet hydrologic conditions, except for the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), which shows lower median elevations. As conditions become drier, Lake Powell's elevations decrease and the differences among alternatives become more pronounced, with operations varying widely at lower water levels.

In the two driest flow categories, the Enhanced Coordination Alternative maintains the highest median reservoir elevations, followed by the Maximum Operational Flexibility Alternative. Both alternatives keep median reservoir elevations well above the critical threshold of 3,500 feet, even during dry periods; therefore, they would expose the fewest number of TCPs to increased visitation. In contrast, the No Action Alternative and the Basic Coordination Alternative have median elevations that fall below this critical threshold in dry hydrologic conditions, and these alternatives would facilitate the greatest access to TCPs.

For Lake Mead, median EOCY elevations also decline as conditions become drier, but the relative performance of each alternative remains consistent. The Supply Driven Alternative (LB Pro Rata approach) consistently has the highest median reservoir elevations across all flow categories, followed by the Supply Driven Alternative (LB Priority approach); therefore, these would expose the fewest number of TCPs to increased visitation. The No Action Alternative consistently has the lowest median elevations, with the CCS Comparative Baseline having the second lowest; these alternatives would facilitate the greatest access to TCPs. Most action alternatives show wide variability in Lake Mead's elevations, except for the Maximum Operational Flexibility Alternative, under which the elevation reliably remains above 975 feet.

Issue 2: How would changes in dam operations affect lake elevations (primarily in Lake Powell and Lake Mead) and river flows downstream, which could impact or sacred sites?

Sacred sites are specific locations that a tribe has identified as sacred because of the sites' traditional religious significance or because the sites are a discrete location for ceremonial use. Sacred sites oftentimes overlap significantly with TCPs and with Indigenous archaeological sites. Accordingly, impacts on sacred sites are qualitatively similar to impacts on archaeological sites. Of primary concern are direct impacts like wave action and wet-dry cycling that could occur from changes in lake levels or impacts on river flows from annual releases. Impacts on archaeological sites are analyzed in detail in **TA 11**, Cultural Resources, and that discussion is summarized here.

At Lake Powell and Lake Mead, continuous inundation of sacred sites or Indigenous archaeological sites helps preserve them better than cycles of flooding and exposure, which increase risks from wave action. The main concern is that dropping lake elevations could expose such sites that were previously underwater, making them vulnerable to wet-dry cycles and wave impacts. As water levels fall, more sites become exposed to these risks at lower elevations. Sites at higher elevations may be less affected by wet-dry cycling and wave action but could become more accessible, depending on their location.

Hydrologic models show that during wet hydrologic conditions, Lake Powell's water levels are projected to remain above 3,660 feet in all scenarios. As conditions get drier, the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain the highest median water levels during the Average Flow Category (12.0-14.0 maf), staying at or above 3,620 feet. These alternatives also perform best in the Critically Dry Flow Category (4.46-10.0 maf), but projected medians are still below 3,580 feet; this means sacred sites or archaeological sites—and any unknown sites—at these elevations would be exposed.

For Lake Mead, the Supply Driven Alternative maintains the highest water levels during both the Average and Critically Dry Flow Categories, followed by the Enhanced Coordination and Maximum Operational Flexibility Alternatives. The Supply Driven Alternative has projected median elevations up to 1,150 feet in the Average Flow Category, while the Enhanced Coordination and Maximum Operational Flexibility Alternatives have medians around 1,100 feet. In the Critically Dry Flow Category, all scenarios would expose sacred sites or archaeological sites and any unknown sites; however, the Supply Driven Alternative could protect more sites, with upper interquartile ranges reaching about 1,120 feet.

This pattern is reflected in the Preservation Risk Model analysis. For Lake Powell, the Enhanced Coordination Alternative is the most robust, with 58 percent of modeled futures meeting the preservation threshold, followed by the Maximum Operational Flexibility Alternative at 36 percent. For Lake Mead, the Supply Driven Alternative is the most robust, with 43 percent of modeled futures meeting the threshold, followed by the Maximum Operational Flexibility Alternative at 37 percent.

For the Colorado River stretches between Glen Canyon Dam and Lake Mead, and between Hoover Dam and Lake Mohave, water release volumes in the Wet (16.0-31.11 maf) and Average Flow Categories generally remain within the range of past annual releases. However, in the Critically Dry Flow Category, median annual release volumes drop below 7.0 maf below Glen Canyon Dam, with the Enhanced Coordination Alternative reaching as low as 5.1 maf. Below Hoover Dam, the median annual flows fall below 8.0 maf, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives dropping to 6.6 maf. As a result, in critically dry hydrologic conditions, lower water levels increase the likelihood of sacred sites or archaeological sites near the riverbanks being exposed.

Below Davis Dam, impacts are expected to be minimal or nonexistent in any flow category. This is because the dams below Lake Mohave are managed to maintain lake elevations or meet targeted water deliveries, and many sections have channelized banks that further reduce exposure risks.

Issue 3: How would changes in dam operations impact natural resources important to Native Americans, including riparian vegetation and wildlife?

Indigenous worldviews do not differentiate between cultural and natural environments, as they do in western science. Under an Indigenous perspective, resources considered separately as cultural or natural are all interconnected and interdependent (Berkes 2018). Human interventions that disrupt these interconnections are considered adverse impacts. This EIS discusses many of these resources, such as water quality, air quality, terrestrial wildlife, and others. Although all resources are considered interconnected, Indigenous oral history and ongoing consultation with Native American groups have identified riparian vegetation communities and aquatic wildlife as resource categories of particular concern along the Colorado River corridor. Accordingly, Reclamation considers riparian vegetation and aquatic wildlife (native and nonnative fish) below. Adverse impacts on these resources important to Native Americans would be addressed though ongoing consultation with the affected tribes.

TA 9, Vegetation, presents in detail the quantitative impacts on riparian vegetation communities and evaluations of which alternatives best support historical vegetation community conditions. Those quantitative analyses are summarized here. Woody riparian vegetation is moderately tolerant of water fluctuations, but if variability increases over a 5-year period, these areas tend to decrease. Conversely, if water level variability decreases annually or over 5 years, woody riparian vegetation may expand.

For Lake Powell, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would maintain woody riparian vegetation most similar to historical conditions. For Lake Mead, the Maximum Operational Flexibility Alternative would best match historical vegetation patterns. However, in the stretch from Hoover Dam to the SIB, these two alternatives would cause vegetation to differ most from historical conditions, leading to greater changes in that area. The Basic Coordination Alternative would be least similar to historical conditions for Lake Powell but would be closest to historical vegetation patterns for Lake Mead and the Hoover Dam to SIB reach. This means no single alternative matches the historical vegetation conditions across all areas.

Most alternatives provide variability closer to historical conditions than the CCS Comparative Baseline in most reaches, except for Hoover Dam to the SIB, where only the Basic Coordination Alternative does so. This suggests that changing current management strategies would benefit much of the analysis area but not the Hoover Dam to SIB reach, unless the Basic Coordination Alternative is chosen.

For the stretch between Glen Canyon Dam and Lake Mead, the alternative that best maintains historical vegetation depends on whether the starting hydrologic conditions are wet or dry. Under dry and critically dry hydrologic conditions, differences between the alternatives become more noticeable, especially in the lowest, median, and peak flows. However, across all alternatives, sub-reaches, and evaluation criteria (habitat area, native species richness, proportion of native species cover, and total annual vegetation cover), the interquartile ranges often overlap, making it hard to identify a clear best or worst alternative for preserving historical vegetation conditions.

Under all alternatives for Lake Powell, Lake Mead, and Hoover Dam to the SIB, the first decade is expected to have greater variability and reduced woody riparian habitats, compared with historical conditions. Conditions improve in the second and third decades, allowing vegetation to recover and be reestablished. If variability prevents woody riparian habitats from forming, the area may shift to another habitat type.

Quantitative impacts on aquatic wildlife are considered in detail in **TA 8**, Biological Resources – Fish and Other Aquatic Species, and those quantitative analyses are summarized here. Decreased water levels at Lake Powell affect lake and river habitats for culturally important native and nonnative fish. Among the alternatives, the No Action Alternative stands out because it increases the amount of exposed river habitat for endangered Colorado pikeminnow and razorback sucker, which is beneficial for these species. However, this also means less lake habitat for sportfish, which could negatively affect recreational fishing.

All alternatives except the Enhanced Coordination and Maximum Operational Flexibility Alternatives keep Lake Powell below critical elevation thresholds (3,598 feet for the Colorado River and 3,600 feet for the San Juan River), thereby increasing river habitat. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are less effective in this regard, as they tend to flood critical habitats and reduce the value of riverine habitat.

No alternative is particularly successful at maintaining Piute Farms Waterfall as a barrier to prevent nonnative fish from moving upstream. On the other hand, all alternatives support native fish passage over the waterfall when it is inundated. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and the CCS Comparative Baseline are the most effective at maintaining the waterfall as a barrier, while the Enhanced Coordination and Maximum Operational Flexibility Alternatives are more likely to allow inundation and fish passage.

For Lake Mead, the alternatives would affect tributary inflow habitats of culturally important fish populations. The No Action Alternative and CCS Comparative Baseline are the most effective at keeping Lake Mead below 1,090 feet for at least 90 percent of months. This helps restrict nonnative fish and maintain the current species composition in the Grand Canyon. However, these lower elevations also hinder native species—such as razorback sucker, flannelmouth sucker, and humpback chub—from moving upstream into Grand Canyon habitats.

The Basic Coordination Alternative performs moderately well in balancing these outcomes. In contrast, the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are less effective, as they more often allow Lake Mead to rise above critical thresholds. This can make it easier for both native and nonnative fish to move upstream.

Among the alternatives, the Supply Driven Alternative (LB Pro Rata approach) is the most reliable for keeping Lake Mead above its historical minimum elevation, which supports greater habitat stability.

Summary Comparison of Alternatives

TCPs are historic properties significant to Indigenous communities, mainly due to their association with culturally important events or individuals, as described in oral traditions. The main impacts on TCPs come from changes in the natural environment caused by managing reservoir levels and water releases, as well as increased exposure and visitation when water levels drop. Adverse impacts on TCPs are addressed through a programmatic agreement and ongoing consultation with tribes, in compliance with the National Historic Preservation Act.

As lake levels fluctuate, TCPs may become more accessible to both tribal members and non-Native visitors. Under wet hydrologic conditions, most alternatives keep Lake Powell's water levels high and exposure of TCPs low, except for the Supply Driven Alternative, which has lower elevations. In dry hydrologic conditions, the Enhanced Coordination and Maximum Operational Flexibility

Alternatives maintain the highest water levels, limiting TCP exposure, while the No Action and Basic Coordination Alternatives result in lower elevations and greater access to TCPs. For Lake Mead, water levels also drop as conditions get drier. The Supply Driven Alternative (LB Pro Rata approach) keeps the highest water levels and limits TCP exposure, while the No Action Alternative and CCS Comparative Baseline have the lowest levels, increasing access to TCPs.

Sacred sites are locations identified by tribes for their religious or ceremonial significance; these siters often overlap TCPs and Indigenous archaeological sites. Impacts on sacred sites are similar to those affecting archaeological sites, with the main concerns being damage from wave action and wet-dry cycling caused by fluctuating lake and river levels. Continuous inundation helps preserve these sites, while exposure due to falling water levels increases risks.

During wet hydrologic conditions, Lake Powell's water levels are expected to remain high, minimizing exposure. As conditions become drier, the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain higher water levels than others but still fall below critical thresholds in extremely dry scenarios, exposing more sites. For Lake Mead, the Supply Driven Alternative maintains the highest water levels and protects more sites, especially in dry hydrologic conditions. For the river stretches between Glen Canyon Dam and Lake Mead, and between Hoover Dam and Lake Mohave, annual water releases in wet and average years generally match historical volumes. In critically dry years, releases drop significantly, increasing the risk of exposing sacred and archaeological sites near riverbanks. Below Davis Dam, impacts are minimal due to managed lake elevations and channelized banks.

Indigenous perspectives view cultural and natural resources as interconnected, so any disruption to these links is a potential impact. Along the Colorado River, riparian vegetation and aquatic wildlife are especially important to Native Americans. Woody riparian vegetation is moderately resilient to water fluctuations, but increased variability over several years can reduce these habitats. For Lake Powell, the Enhanced Coordination and Maximum Operational Flexibility Alternatives best maintain vegetation similar to historical conditions. For Lake Mead, the Maximum Operational Flexibility Alternative performs best, while the Basic Coordination Alternative is closest to historical conditions for Lake Mead and the Hoover Dam to SIB reach. No single alternative matches historical vegetation patterns across all areas, but most alternatives perform better than the CCS Comparative Baseline in most reaches.

Lower water levels at Lake Powell benefit endangered river species (Colorado pikeminnow and razorback sucker) by increasing their habitat, especially under the No Action Alternative; however, lower water levels reduce lake habitat for sportfish. Most alternatives (except the Enhanced Coordination and Maximum Operational Flexibility Alternatives) keep Lake Powell below critical thresholds, favoring river habitats. The Enhanced Coordination and Maximum Operational Flexibility Alternatives tend to flood critical habitats, reducing the river habitat value.

For Lake Mead, the No Action Alternative and CCS Comparative Baseline maintain lower water levels; this helps restrict nonnative fish but also limits upstream movement of native fish. The Basic Coordination Alternative offers a moderate balance. The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives more often allow Lake Mead to rise above critical thresholds, which can facilitate movement for both native and nonnative fish. The Supply Driven Alternative (LB Pro Rata approach) is most reliable for maintaining Lake Mead above its historical minimum, supporting habitat stability.

3.14 Recreation

3.14.1 Affected Environment

This section describes existing recreational conditions along the Colorado River system from Lake Powell to the SIB. The analysis focuses on four primary recreational resources: shoreline public use, reservoir boating, river and whitewater boating, and sport fishing. For a more detailed description of these recreational resources, please reference **Section TA 14.1**, Recreation, Affected Environment.

Geographic Reaches

Lake Powell and Glen Canyon National Recreation Area

Glen Canyon NRA receives approximately three to five million visitors annually (NPS 2025b). Lake Powell is the primary recreational feature within Glen Canyon NRA, and it supports swimming, power boating, houseboating, water skiing, fishing, personal watercraft use, nonmotorized boating, hiking, camping (developed and primitive), and viewing of cultural and geologic resources.

Recreational boating is the dominant activity on Lake Powell, with nearly two million visitors accessing the reservoir by private or rental boats (NPS 2025c). Operability of boat ramps and marinas is highly dependent on the lake's elevation. Several ramps and the Dangling Rope Marina have been closed in the last decade due to low water levels, requiring boaters to concentrate use at fewer facilities and increasing congestion at remaining ramps. The NPS is pursuing new ramps and facility modifications to maintain boating access at lower pool elevations (NPS 2025d).

Access to Rainbow Bridge National Monument has become more limited as lake levels have declined. At elevations below 3,544 feet, concession-operated boat tours can no longer reliably reach the area, and private boaters often must traverse mud, debris, and shallow water between the shoreline and the established trail (NPS 2021b). This has substantially reduced access for many visitors.

Additional shoreline issues at Lake Powell include the following:

- Harmful algal blooms: Increasingly frequent harmful algal bloom events can result in temporary closures of water-based recreation areas to protect public health (Deemer et al. 2023).
- Quagga mussels**:** Established populations of quagga mussels encrust canyon walls, shorelines, boats, and infrastructure. Accumulated shells along beaches can create hazards for visitors and pets and increase facility maintenance needs (NPS 2016).
- Newly exposed lands**:** Declining water levels have exposed approximately 100,000 acres of previously inundated Glen Canyon, revealing arches, side canyons, rock formations, and

archaeological sites (Baker 2022; Kolbert 2021). These areas provide new hiking and sightseeing opportunities but are fragile and vulnerable to erosion and vandalism.

Glen Canyon Dam to Lake Mead (Colorado River Corridor)

The 15.5-mile reach downstream of Glen Canyon Dam to Lees Ferry is located within Glen Canyon NRA and is used extensively by anglers, campers, commercial float trips, and private boaters. Warmer water temperatures in recent years have increased use by paddle boarders, kayakers, and canoeists.

Downstream, GCNP begins at the confluence of the Colorado and Paria Rivers. GCNP, a United Nations Educational, Scientific and Cultural Organization World Heritage Site, receives approximately four to six million visitors annually and provides a range of backcountry and river-based experiences (NPS 2025e). Camping along the Colorado River corridor occurs on undeveloped sandbars. The number, size, and suitability of campsites vary over time due to the fluctuating size of sandbars, which are affected by dam operations, tributary floods, vegetation encroachment, and management closures. The river corridor also borders tribal lands for approximately 108 miles, where the Navajo Nation, Hualapai Tribe, and other tribes manage additional shoreline recreation, such as guided rafting, camping, hunting, and hiking. Access to tribal lands requires permits from the respective tribes.

Lake Mead National Recreation Area

Lake Mead NRA encompasses Lake Mead, Lake Mohave, and the surrounding desert landscapes. Lake Mead NRA receives roughly five to eight million visitors annually (NPS 2025f). The primary recreational activities include boating, fishing, water sports, swimming, camping, hiking, and wildlife viewing. The Overton Wildlife Management Area and other shoreline sites provide additional opportunities for hunting, birdwatching, and photography.

Declining reservoir elevations at Lake Mead have exposed extensive mudflats in several shoreline areas. Visitors attempting to "chase the waterline" on foot or by vehicle for fishing and shoreline access have sometimes become stuck in wet, unstable sediment, necessitating rescues and increasing safety concerns. Multiple launch ramps and some marinas have closed because water levels dropped below critical elevations; these closures have concentrated use at the remaining facilities and contributed to crowding and operational challenges.

Water quality concerns, such as harmful blue-green algal blooms and rare but serious incidents involving *Naegleria fowleri,* which is known as the brain-eating amoeba, are emerging issues for recreation management as lake temperatures warm (NPS 2022).

Lower Colorado River Reaches (Davis Dam to the SIB)

Downstream of Hoover Dam, recreation along the Colorado River is supported by a network of public recreation areas, national wildlife refuges (NWRs), and state parks, including Davis Camp, Laughlin/Bullhead City, Havasu NWR, Lake Havasu State Park, Bill Williams River NWR, Cibola NWR, Imperial NWR, Martinez Lake, and various small shoreline facilities near Yuma.

Across these reaches, visitors engage in boating, houseboating, fishing, water skiing, swimming, paddling, hunting, hiking, wildlife viewing, and camping. Lake Havasu, in particular, is a high-use destination for motorized boating, angling, spring break, and family recreation. River segments adjacent to NWRs provide more natural settings valued for wildlife viewing, hunting, and low-density boating.

Recreational Uses

Shoreline Public Use

Shoreline public use in the study area is supported by marinas, boat launch ramps, docks, campgrounds, and access points to major destinations. These facilities provide access for day use, extended boating trips, camping, hiking, and viewing of natural and cultural resources. Fluctuations in reservoir elevations influence the operability and safety of these facilities. Declining water levels can result in temporary or long-term closures of ramps and marinas, relocation or modification of facilities, congestion at remaining access points, and reduced or more difficult access to popular shoreline destinations.

Reservoir Boating

Reservoir boating throughout the system is directly affected by fluctuating water levels. As reservoir elevations decline, navigational hazards (for example, exposed rocks, sandbars, and constricted channels) increase, and safe boating capacities decrease. Management responses include the placement of buoys and markers, installation of warning signs, and formal closure of unsafe areas.

At Lake Powell, the safe boating capacity at full pool (elevation 3,700 feet) is approximately 17,865 boats at one time, based on the surface area and a density of 9 acres per boat. As elevations decline, the usable surface area and navigability decrease correspondingly. Quagga mussel infestations further complicate operations by fouling boats, infrastructure, and shorelines.

At Lake Mead, the safe boating capacity at full pool is approximately 17,000 boats. In the upstream arms, sediment deposition and receding water levels have created shallow, poorly defined channels. When lake elevations fall below approximately 1,170 feet, the upper end of Lake Mead becomes too shallow for most motorized boats to navigate upstream into the lower Grand Canyon. As Lake Mead has receded, the Colorado River has incised into deposited sediments near Pearce Ferry, forming a new high-hazard rapid (Pearce Ferry Rapid) that blocks upstream motorized navigation and has altered takeout operations.

Lake Mohave and Lake Havasu are typically managed to meet relatively stable monthly target elevations; therefore, large changes in reservoir boating capacity or navigability are not anticipated under current operations and are therefore not included in the environmental analysis.

River and Whitewater Boating

Whitewater boating is the primary recreational activity on the Colorado River between Lees Ferry and the downstream takeouts at Diamond Creek or Pearce Ferry. Trips may be commercial or private, use a variety of boat types, and range up to 25 days in length. GCNP staff manages river use under the Colorado River Management Plan, which establishes limits on daily launches, group size, trip length, and the timing of motorized and nonmotorized use (NPS 2006).

Navigability and the user experience are influenced by discharge levels, debris fan rapids, and changing channel conditions. Lower flows and increased side-canyon debris can make certain rapids more technically demanding.

Flow levels are a key determinant of whitewater trip quality and safety (Bishop et al. 1987; Shelby et al. 1992; Hall and Shelby 2000; Stewart et al. 2000; Neher et al. 2017). Studies and user surveys indicate that flows below about 10,000 cubic feet per second (cfs) and above about 45,000 cfs are generally considered less than optimum, while flows between approximately 20,000 and 26,000 cfs are considered optimal for most whitewater users (Shelby et al. 1992; Bishop et al. 1987; Neher et al. 2017). Flows of 8,000–9,000 cfs are regarded as the minimum acceptable levels for safely running trips with passengers (Bishop et al. 1987; Stewart et al. 2000).

Downstream of Hoover Dam, the proposed alternatives are not expected to substantially affect river or whitewater boating conditions between Hoover Dam and the SIB.

Sport Fishing

Sport fishing is an important recreational use across the study area. Although specific elevation thresholds for angler satisfaction are not well defined, fishing quality is closely linked to reservoir habitat, water temperature, access via ramps and marinas, and boat navigability.

Lake Powell supports warmwater fisheries, including for striped bass, smallmouth bass, largemouth bass, walleye, catfish, and panfish. Forage species, such as threadfin shad, are sensitive to temperature changes and influence predator populations.

The 15.5-mile tailwater reach below Glen Canyon Dam supports a Blue Ribbon[14] rainbow trout fishery at Lees Ferry. Historically, cold-water releases limited survival and reproduction of warmwater species entrained from Lake Powell. Recent warmer and lower-oxygen releases have increased the risk of establishment and recruitment of nonnative predators, such as smallmouth bass, which potentially reduces trout quality. Please refer to **TA 14**, Recreation, for more information on rainbow trout dynamics in this reach.

Lake Mead and Lake Mohave support diverse warmwater fisheries (for striped bass, largemouth bass, catfish, panfish, and stocked trout). Low reservoir levels have affected hatchery operations at Lake Mead, leading to facility modifications and water supply changes. Farther downstream, Lake Havasu and the lower river reaches support striped bass, largemouth and smallmouth bass, catfish, crappie, sunfish, and other species, with some areas subject to seasonal closures (for example, Cibola Lake) to protect wildlife.

Overall, sport fishing opportunities remain widespread throughout the system but are sensitive to changes in hydrology, water temperature, water quality, and access conditions associated with reservoir elevations and dam operations.

[14] A Blue Ribbon fishery designation indicates a high-quality recreational fishery that meets specific criteria, including water quality, natural reproduction capacity, and management strategies.

3.14.2 Environmental Consequences

Methodology

Consistent with Reclamation's 2007 Final EIS and 2024 Final SEIS, the analysis builds on traditional threshold-based evaluation methods by integrating DMDU concepts, including robustness heat maps and vulnerability bar plots. These tools highlight how each alternative performs across a wide range of plausible hydrologic futures with regard to shoreline public use facilities, reservoir boating and navigational hazards, whitewater boating, and sport fishing. Refer to **Section 3.2.6**, Decision Making under Deep Uncertainty, for an overview of interpreting the DMDU robustness heat maps and vulnerability bar plots.

Method Used to Assess Shoreline Public Use Facilities

The evaluation of shoreline facilities relies on thresholds provided by the NPS that identify reservoir elevations at which specific marinas, docks, and launch ramps require modification, relocation, or closure. These thresholds serve as impact indicators for the loss or degradation of shoreline public use. Using the DMDU framework, the analysis examines the percentage of futures in which a given alternative maintains a minimum proportion of recreational sites (for example, 0.7 for Lake Powell and 0.8 for Lake Mead) operable throughout the summer high-use season (May 31–August 31). This period was selected because visitation is highest, and operational disruptions have the greatest impact on user experiences and local economies. Representative facilities were selected from Lake Powell and Lake Mead to align with the regional economic modeling (see **TA 16**, Socioeconomics).

Method Used to Assess Reservoir Boating and Navigation Hazards

Reservoir boating impacts are analyzed using critical navigational thresholds identified in the 2007 Final EIS and continued in the 2024 Final SEIS. Threshold elevations indicate levels below which safe navigation becomes substantially impaired due to shallow channels, newly exposed hazards, or blocked passageways. DMDU outputs evaluate the frequency with which each alternative avoids falling below these elevations. This approach highlights the reliability of each alternative in maintaining safe boating conditions over multiple hydrologic futures.

Method Used to Assess Whitewater Boating

The evaluation of whitewater boating relies on minimum flow thresholds known to influence navigability, safety, and trip management. Prior studies (Bishop et al. 1987; Stewart et al. 2000) identify 8,000 cfs as the preferred minimum daytime flow for whitewater boating with passengers, 5,000 cfs as a low-flow threshold below which trip disruption and safety hazards increase, and 20,000–26,000 cfs as the preferred range for optimal whitewater boating experiences. DMDU heat maps assess the percentage of futures in which the alternatives maintain flows above the minimum thresholds during the daytime (7:00 a.m. to 7:00 p.m.) across the modeling period.

Methods Used to Assess Ferry and Taxi Boat Services

Thresholds provided by the Utah Department of Transportation (UDOT 2025) identify key elevations required for ferry operations, most notably 3,575 feet. The analysis evaluates whether reservoir elevations under each alternative would sustain these services or require extended closure.

Methods Used to Assess Sport Fishing

Reservoir sport fishing is influenced primarily by habitat availability, shoreline complexity, and thermal conditions. Because no discrete elevation thresholds exist for fishing suitability, DMDU is not used for reservoir sport fishing; instead, the analysis focuses on how general elevation trends under each alternative influence fish habitat.

A more detailed analysis (**TA 8**, Biological Resources – Fish and Other Aquatic Species) using DMDU information was conducted for the Lees Ferry rainbow trout fishery, where water temperature is directly linked to recreational quality and species viability.

Impact Analysis Area

The impact analysis area for recreation aligns with the general analysis area, which encompasses the Colorado River corridor from the full pool elevation of Lake Powell to the SIB.

Assumptions

- The analysis assumes that the demand for recreational opportunities will either remain constant or increase over time. This assumption forms the basis for evaluating impacts on activities such as reservoir recreation, fishing, and whitewater boating.
- The analysis considers 5,000 cfs and 8,000 cfs as two levels at which commercial and private boaters may experience navigability challenges (Bishop et al. 1987; Stewart et al. 2000; Shelby et al. 1992).
- Additional assumptions related to modeling are considered in the analysis, contributing to the accuracy and reliability of the hydrologic models used to anticipate impacts resulting from various actions.

Impact Indicators

- Threshold reservoir elevations
- Threshold river flows
- Water temperatures

Issue 1: How would the management of reservoir elevations affect recreation?

Lake Powell

Shoreline Recreational Facilities

Reservoir elevations exert a direct influence on the operability of Lake Powell's recreational infrastructure. Many of Lake Powell's primary launch ramps, marinas, and courtesy docks become inaccessible or require substantial modification when lake levels fall below the thresholds identified by the NPS (see **Table TA 14-3** in **TA 14**, Recreation). The DMDU results (**Figure TA 14-1** in **TA 14**, Recreation) illustrate that under the Enhanced Coordination and Maximum Operational Flexibility Alternatives, Lake Powell is more robust at maintaining adequate elevations to keep a majority of recreational facilities open during the critical summer season. These alternatives achieve this performance in 45 percent and 26 percent of futures, respectively, indicating a modest but meaningful improvement over the other alternatives.

In contrast, the CCS Comparative Baseline and the Basic Coordination, Supply Driven (both LB Priority and LB Pro Rata approaches), and No Action Alternatives provide much lower robustness, maintaining 70 percent of recreational sites in only 13 to 17 percent of futures. Under these alternatives, periods of low water would be more likely, which could result in recurring closures of boat launch ramps, restricting marinas to limited operability, and reducing shoreline access for day users, campers, and boaters. Visitors could experience longer wait times, congested remaining ramps, and reduced access to preferred boating destinations. Taken together, the projected reservoir conditions suggest that under most alternatives, the reliability of Lake Powell's shoreline public use facilities would decline from historical norms.

Boating Navigation

Safe boating access at Lake Powell depends strongly on maintaining reservoir elevations above the 3,620-foot threshold. Elevations below this level expose hazards and constrict navigation channels. The DMDU analysis shows that the Enhanced Coordination and Maximum Operational Flexibility Alternatives offer the greatest robustness at maintaining elevations above this threshold, doing so in roughly 80 percent of modeled futures. These alternatives would support safer boating conditions under a wider range of hydrologic conditions and preserve access to many of the canyon environments that are central to the Lake Powell recreational experience.

The other alternatives perform moderately to poorly in this regard. The Basic Coordination and No Action Alternatives, along with the CCS Comparative Baseline, achieve the threshold in approximately 60 percent of futures, while the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintains the threshold in approximately 40 percent of futures. Under these worse-performing alternatives, Lake Powell could experience prolonged periods during which safe passage through major navigation corridors is limited, reducing the quality and quantity of recreational boating opportunities across a wider range of hydrologic futures. All alternatives show poor performance in maintaining a Lake Powell elevation of 3,620 feet or above in 85 percent or more futures, indicating that the long-term return to historically common elevation levels is unlikely.

Sport Fishing

Sport fishing in Lake Powell is sensitive to changes in reservoir elevation because habitat complexity diminishes as water recedes. The Maximum Operational Flexibility and Enhanced Coordination Alternatives, which are more robust at achieving higher median elevations around 3,600 feet, would help preserve a more diverse array of shallow-water habitats favored by desirable warmwater sportfish, including largemouth bass, bluegill, and crappie. Conversely, the lower-elevation alternatives cluster around 3,560 feet and would result in diminished shallow-water habitat, promoting conditions that favor smallmouth bass and reducing the productivity of the fishery for many anglers. Thus, the alternatives that sustain higher average reservoir levels would provide more favorable sport fishing conditions throughout the year.

Ferry and Taxi Boat Services

Ferry and taxi boat services at Lake Powell require relatively high reservoir elevations to maintain safe docking and transit conditions. The ferry becomes inoperable at elevations below 3,575 feet. Because all alternatives frequently fall below this threshold across much of the modeled period, ferry service interruptions or full discontinuation would be a near-constant condition under all operational strategies. Only substantial engineering modifications or relocation efforts would restore reliable ferry service under extended drought conditions.

Lake Mead

Shoreline Recreational Facilities
Lake Mead recreational infrastructure is sensitive to threshold elevations. Many of the reservoir's launch ramps, marinas, and shoreline access points become impaired as water levels retreat, and steep, unstable slopes emerge. The DMDU analysis shows that the Supply Driven Alternative, particularly the Pro Rata approach, is most effective at maintaining at least 80 percent of recreational facilities during the summer season. While this alternative preserves opportunities at Lake Mead, it also reflects trade-offs for Lake Powell. The Maximum Operational Flexibility Alternative performs moderately well, though not at the same level as the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches).

Under the CCS Comparative Baseline and the Enhanced Coordination Alternative, Basic Coordination Alternative, and especially the No Action Alternative, Lake Mead experiences much lower reliability in maintaining recreational sites. These deficiencies translate into recurring closures, reduced or eliminated launching opportunities, stranded infrastructure, and a substantial decline in the quality of recreational access. As reservoir conditions deteriorate under these alternatives, visitor safety concerns would increase, and more intensive management interventions would be needed to maintain even modest levels of access.

Boating Navigation
Maintaining Lake Mead above the 1,170-foot threshold is essential for preserving upstream navigation into the lower Grand Canyon. The analysis shows that only the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) provides a high likelihood of maintaining Lake Mead above this level for any substantial portion of time, with success rates approaching 80 percent of futures. This alternative would help reduce navigation hazards, prevent extensive mudflat exposure, and sustain limited upstream boating opportunities.

The other alternatives show weaker performance, with the Maximum Operational Flexibility, Enhanced Coordination, and Basic Coordination Alternatives maintaining the threshold in far fewer futures. The No Action Alternative and CCS Comparative Baseline exhibit the poorest performance. Under these less favorable scenarios, large areas of the reservoir would expose thick mudflats and shallow delta formations, making it dangerous or impossible for boaters to access several parts of the reservoir. These conditions would also exacerbate congestion at the limited number of remaining deep-water access points.

Issue 2: How would the management of releases from Glen Canyon Dam affect recreation, including from changes in water temperature?

Whitewater Boating

Whitewater boating conditions below Glen Canyon Dam depend heavily on reliable daytime flows that allow large commercial rafts to safely navigate rapids and manage trip logistics. The analysis shows that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs the strongest in maintaining flows at or above the 8,000 cfs minimum threshold, providing favorable conditions in approximately 86 percent of futures. This alternative helps ensure that commercial and private boating groups face fewer low-water hazards, allowing for safer, smoother navigation.

The Basic Coordination Alternative also performs well, while the CCS Comparative Baseline and the No Action, Maximum Operational Flexibility, and Enhanced Coordination Alternatives exhibit diminishing performance. The Enhanced Coordination Alternative, in particular, maintains the 8,000 cfs threshold in only 14 percent of futures, indicating substantial vulnerability to flows falling below the preferred safety conditions. As flows weaken, rafting parties could encounter more exposed rocks, shallower rapids, longer portaging distances, and increased risks of boating incidents. These hazards directly affect the quality, reliability, and safety of the Grand Canyon whitewater recreational experience.

When evaluating flows above the 5,000 cfs threshold, which are considered minimally adequate for boating, the analysis finds that the Enhanced Coordination and the Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) maintain this threshold in nearly all futures. While these flows may not provide optimal conditions, they reduce the likelihood of severe navigational hazards. The other alternatives perform moderately to poorly, elevating risks for boaters and contributing to unpredictable trip conditions.

Overall, the alternatives that maintain higher flows offer substantially better protection of the whitewater recreational quality. Conversely, the alternatives that produce more frequent low-flow conditions increase safety risks, impede access to campsites, and alter trip durations.

Sport Fish Populations

Recreational fishing below Glen Canyon Dam, particularly at Lees Ferry, is highly sensitive to changes in water temperature. Rainbow trout experience thermal stress when temperatures exceed 20 °C (68 °F), while warmwater species, such as smallmouth bass, benefit from elevated temperatures and potentially expand their range.

The Enhanced Coordination Alternative offers the highest likelihood of maintaining cooler water temperatures, meeting the preferred temperature performance in 71 percent of futures. Under this alternative, the likelihood of maintaining a high-quality trout fishery is greatest. The Maximum Operational Flexibility Alternative also performs moderately well, while the No Action and Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) perform poorly, allowing temperatures to exceed optimal thresholds in a large proportion of futures.

Under warmer and drier hydrologic futures, all alternatives become more vulnerable to undesirable temperature increases. Under such conditions, rainbow trout populations may decline, and warmwater species may proliferate, potentially altering recreational fishing patterns and diminishing the unique value of the Lees Ferry fishery. Without management interventions, such as cold-water bypass infrastructure, the ability to maintain high-quality trout fishing will remain constrained across all alternatives.

Summary Comparison of Alternatives

The alternatives vary considerably in their ability to sustain recreational resources over the full analysis period. The alternatives that favor higher Lake Powell elevations, such as the Enhanced

Coordination and Maximum Operational Flexibility Alternatives, offer the greatest benefits for Lake Powell–based recreational resources. These alternatives help preserve access to boat ramps and marinas, maintain more reliable boating corridors, and sustain more diverse sport fishing opportunities. By contrast, the alternatives that prioritize meeting compact delivery obligations through downstream releases, such as the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), perform more poorly for Lake Powell's recreational infrastructure.

At Lake Mead, the pattern is reversed. The alternatives that retain more water downstream, specifically the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), perform best at keeping facilities open and maintaining safe boating conditions. The Maximum Operational Flexibility and Enhanced Coordination Alternatives provide moderate benefits, while the No Action Alternative and the CCS Comparative Baseline offer the least reliable performance for Lake Mead–based recreation.

For whitewater boating in the Grand Canyon, the alternatives also yield varying results. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintains the highest likelihood of meeting the preferred 8,000 cfs flow threshold, ensuring safe and high-quality rafting opportunities. The Enhanced Coordination and Maximum Operational Flexibility Alternatives perform poorly in this regard, creating greater risks for boaters and reducing the reliability of commercial trip planning.

In terms of water temperature and sport fishing below Glen Canyon Dam, the Enhanced Coordination Alternative performs most favorably, helping sustain the cold-water conditions required for a thriving rainbow trout population. The Maximum Operational Flexibility Alternative also provides moderate support for cooler temperatures. The alternatives that prioritize downstream deliveries at the expense of upstream storage tend to worsen temperature conditions and increase the prevalence of warmwater predators.

Overall, no alternative fully protects all recreational resources throughout the Basin under extended drought conditions. Instead, each alternative presents a unique set of trade-offs. Those alternatives that prioritize upstream reservoir elevations tend to support recreation at Lake Powell but reduce downstream releases needed for whitewater boating and temperature control; those that emphasize deliveries to the Lower Basin improve Lake Mead recreation but undermine conditions in Lake Powell and Lees Ferry. These trade-offs underscore the Basin-wide challenge of managing limited water supplies while simultaneously supporting diverse recreational resources that rely on adequate water levels and river flows.

3.15 Dams and Electrical Power Resources

3.15.1 Affected Environment

This section provides a summary of the infrastructure and spillway conditions and hydropower capacity and generation of the four primary dams and reservoirs in the analysis area of the Colorado River corridor from the full pool elevation of Lake Powell to the SIB. These four dams and reservoirs are Glen Canyon Dam and Lake Powell, Hoover Dam and Lake Mead, Davis Dam and

Lake Mohave, and Parker Dam and Lake Havasu. For additional information and the full discussion of the affected environment and environmental consequences, please refer to **TA 15**, Dams and Electrical Power Resources.

This section addresses the interplay between reservoir elevations and dam releases, and how they influence dam spillway and safety conditions, power generation, and capacity. It also provides the context necessary for evaluating the effects of the alternatives on dams and electrical power resources.

For hydroelectric power resources, the amount of electrical power generated is directly related to the amount of water passing through the power plant turbines and the force, or "head," of the water as it moves through the turbines. The pressure difference between the lake reservoir elevation and a power plant's generators influences the head of the water. The higher the reservoir elevation, the greater the head the water can exert as it passes through the turbines. Higher reservoir elevations allow greater power production, and conversely, if reservoirs drop below a specified elevation (the minimum power pool), power production is not possible.

From a life safety perspective, keeping reservoir water levels below the spillway crest is essential for dam and public safety. Minimizing spillway use preserves the water supply, maintains flood storage capacity, and reduces wear and tear on spillway infrastructure. Maintaining lower reservoir levels allows inflow to be routed through controlled outlets, respond to spring runoff, and protect life safety downstream.

This section also provides the context for analyzing the effects of the alternatives on electricity rates and the market value of electricity. Reclamation operates and maintains the Glen Canyon, Hoover, Davis, and Parker Dams and the Western Area Power Administration (WAPA) is responsible for marketing and transmitting the power generated at these facilities across the Upper and Lower Colorado River Basins (Reclamation 2007a).

Glen Canyon Dam and Lake Powell

Glen Canyon Dam is located in Page, Arizona, and is a concrete arch dam rising 710 feet with a 35-foot-wide roadway connecting the dam's spillways. The dam's reservoir, Lake Powell, has a water storage capacity of 25.16 maf and a maximum reservoir elevation of 3,711 feet. The dam and reservoir are operated and maintained by Reclamation's Glen Canyon Field Division in Page, Arizona. Refer to **Figure TA 15-2** in **TA 15**, Dams and Electrical Power Resources.

Reservoir operations are managed to maintain the water surface elevation near or below 3,700 feet, which is the normal operating level. While operating above this elevation is possible, operational preference is to minimize occurrences above this threshold to protect spillway infrastructure. The maximum water surface elevation of 3,711 feet marks the upper limit of safe reservoir storage, beyond which the risk to the spillway and associated structures increases. Another important operational consideration is maintaining adequate vacant storage above elevation 3,684 feet on January 1, which provides the necessary capacity to manage spring runoff inflows.

The Glen Canyon Dam power plant has eight generators with a maximum combined capacity of 1,320 megawatts (MW) at a reservoir elevation of 3,700 feet (Reclamation 2016). At minimum power pool, the power plant has an estimated physical capacity of 630 MW. The power plant's physical capacity to generate power has recently been affected by decreases in Lake Powell reservoir elevations due to drought conditions. The decreases in elevation have led to lower head, which, combined with reduced annual releases, has reduced power generation since 2007. Please reference **Figure TA 15-3** and **Figure TA 15-4** in **TA 15**, Dams and Electrical Power Resources.

Hoover Dam and Lake Mead

Hoover Dam is located in Black Canyon on the Arizona–Nevada state line, approximately 35 miles southeast of Las Vegas, Nevada. The dam and its reservoir, Lake Mead, are operated and maintained by Reclamation's Lower Colorado River Region. Hoover Dam is a concrete gravity-arch structure standing 726 feet high with a crest length of 1,244 feet. Lake Mead has a water storage capacity of 30.2 maf and a maximum reservoir elevation of 1,232 feet. Refer to **Figure TA 15-5** in **TA 15**, Dams and Electrical Power Resources.

Under normal conditions, nearly all Colorado River flow passes through the turbines, with the spillways and outlet works used only in exceptional circumstances. The maximum safe channel capacity is estimated to be 40,000 cfs. The largest release from Hoover Dam (excluding test releases) occurred in July 1983, with 24,700 cfs discharged through the spillways and 26,100 cfs through the power plant penstocks. Maximum combined power plant and river outlet works releases were 74,405 cfs in June 1998 during testing of the outlet works gates. Current operations aim to keep Lake Mead below 1,219.6 feet as much as possible. While limited operations above this level have occurred historically, it is preferred to minimize time spent in the flood control space. The elevation of the bottom of the spillway drum gate is 1,205.4 feet. Operating below this elevation is desired because elevations above this point rely on mechanical gate function, where the risk of failure increases. The most critical elevation threshold is 1,226.9 feet. This elevation corresponds to a spillway discharge exceeding 40,000 cfs and represents an imminent emergency.

The Hoover Dam power plant has 17 commercial generators with a maximum combined capacity of 2,074 MW. The power plant requires a minimum Lake Mead elevation of 950 feet to produce power. At minimum power pool, the power plant has an estimated capacity of 117 MW. The optimal elevation for hydropower production at Lake Mead is 1,035 feet. At this elevation or greater, hydropower can be produced at or above market value. With current generators, if the elevation drops below 1,035 feet, operating costs will exceed the value of the hydropower produced. The power-generating capacity of Hoover Dam has been affected by drought conditions. The drop in Lake Mead's elevation has reduced head, lowering electric power output. Please reference **Figure TA 15-6** and **Figure TA 15-7** in **TA 15**, Dams and Electrical Power Resources.

Davis Dam and Lake Mohave & Parker Dam and Lake Havasu

Davis Dam is a 320-foot-tall, rock- and earth-fill gravity dam, rising 140 feet above the Colorado River. The dam spans the border of Arizona and Nevada in Pyramid Canyon and is 67 miles downstream from Hoover Dam. Its dam crest is 1,600 feet long and 50 feet wide. Its reservoir, Lake Mohave, has a water storage capacity of 1.8 maf and a maximum reservoir elevation of 647 feet. Davis Dam is operated and maintained by Reclamation's Davis Dam Field Division, which is part of the Lower Colorado Basin Dams Office.

Parker Dam, currently the deepest dam in the world, is a concrete arch structure, 320 feet tall, with 73 percent of its height below the original stream bed elevation of the Colorado River. The dam is on the Arizona–California border and lies 88 miles downstream from Davis Dam. The dam has a crest length of 856 feet and a width of 39 feet. The dam's reservoir, Lake Havasu, has a storage capacity of 646,200 af and a maximum reservoir elevation of 450 feet. Parker Dam is operated and maintained by Reclamation's Parker Dam Field Division of the Lower Colorado Basin Dams Office.

Normal releases from Davis and Parker Dams are made through the power plant turbines with the spillway and outlet works in the closed position. The safe downstream channel capacity on the river is 40,000 cfs.

The Davis Dam power plant has four 51.75 MW generators and one 48 MW generator for a total capacity of 255 MW. The Parker Dam power plant has four 30 MW generators, totaling 120 MW, with a discharge capacity of 22,000 cfs (Reclamation 2023c). Drought conditions have had less impact on the capacity at the Davis and Parker power plants than at the Hoover and Glen Canyon power plants because the elevations of Lake Mohave and Lake Havasu reservoirs have remained relatively constant. Both dams are what is referred to as "run of the river," meaning they use the energy of the river's natural flow, with some flexibility to control releases. Drought-induced reductions in river flow have resulted in a decline in electric power generation at these power plants. Please refer to **Figure TA 15-8** in **TA 15**, Dams and Electrical Power Resources.

Hydroelectric Power Distribution

This section provides a high-level summary of hydroelectric power distribution. Please refer to **Section TA 15.1.4**, Hydroelectric Power Distribution, in **TA 15**, Dams and Electrical Power Resources, for a more in-depth discussion of the topic and a variety of associated topics, including scheduling; load following, generation, and regulation; reliability standards; Basin Funds; emergencies and outages; transmission system; power marketing; and rates.

Hydroelectric power generation can be adjusted operationally through a coordinated effort between WAPA and Reclamation. This operational flexibility allows WAPA to quickly and efficiently increase or decrease generation in response to customer demand. WAPA markets long-term firm capacity and energy; short-term, firm capacity and energy; and non-firm energy. WAPA sets rates for firm electric service from federal hydropower projects in its marketing territory, in accordance with Department of Energy regulations and applicable federal statutes. Customers pay rates that align specifically with the project from which they buy power.

WAPA has a public rate-setting process that includes collaborative planning, a public comment period, and information and comment forums. A notice in the Federal Register announces proposed rates before the comment periods, and then another notice is issued with final rates at the end of the process. WAPA has various wholesale customers, including municipal utilities, federal and state public power facilities, rural electric cooperatives, and tribal entities. Power rates are set so that revenues are sufficient to cover all costs assigned to power within the required time periods. Retail rates are those paid by end users (residential, commercial, and industrial customers of WAPA's wholesale customers). The retail rates charged by not-for-profit entities are normally set to cover system operations and capital costs. As the costs of these individual components change, the retail rates are adjusted to ensure that enough revenue is collected to meet the utility's financial obligations.

3.15.2 Environmental Consequences

This section summarizes the analysis of the effects of the alternatives on the minimum power pool for Lake Powell and Lake Mead; the power capacity of the Glen Canyon Dam and Hoover Dam power plants; the power generation of the Glen Canyon Dam, Hoover Dam, Davis Dam, and Parker Dam power plants; the spillway condition and life safety of Glen Canyon Dam and Hoover Dam; and electricity rates and the market value of the electricity.

The spillway condition, life safety, and hydropower capacity of the Davis Dam and Parker Dam are not analyzed because Lake Mohave and Lake Havasu reservoirs have historically remained relatively constant, and their elevations are expected to remain so under all alternatives. Both Lake Mohave and Lake Havasu would continue to be operated under a rule curve that provides specific target elevations at the end of each month (refer to **Section TA 3.1.8**, Davis Dam to Lake Havasu, in **TA 3**, Hydrologic Resources).

For additional detail and the full analysis of effects, please refer to **Section TA 15.2**, Environmental Consequences, in **TA 15**, Dams and Electrical Power Resources.

Methodology

WAPA's CRSP Python-based (CRiSPPy) model and Reclamation's CRSS model and DMDU analysis framework inform the basis for the effects analysis. For additional information on the methodology used, please refer to **Section 3.2.6**, Decision Making under Deep Uncertainty; **Appendix A**, CRSS Model Documentation; and **Section TA 15.2.1**, Methodology, in **TA 15**, Dams and Electrical Power Resources.

Impact Analysis Area

The analysis area for Issues 1–4 encompasses the four primary dams in the Colorado River corridor from the full pool elevation of Lake Powell to the SIB: Glen Canyon Dam and Lake Powell reservoir, Hoover Dam and Lake Mead reservoir, Davis Dam and Lake Mohave reservoir, and Parker Dam and Lake Havasu reservoir. The analysis area for Issue 5 comprises the WAPA retail power customers of Glen Canyon Dam power that are in the states of Arizona, Colorado, Nevada, New Mexico, Utah, Wyoming, and Texas.

Assumptions

All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell, Lake Mead, or both (refer to **Sections 2.6–2.8**). Unless otherwise specified, impacts reflect modeling assumptions about voluntary conservation behavior.

The Lower Basin electrical generation and capacity modeling results are direct outputs from the CRSS model. Refer to **Appendix A**, CRSS Model Documentation, for more details related to model assumptions and documentation. The Glen Canyon Dam electrical generation and capacity modeling results are direct outputs from the CRiSPPy model. For additional information and modeling assumptions, please refer to *CRiSPPy: An Advanced Hydropower Scheduling Tool for the Colorado River Storage Project* (Ploussard et al. 2025). The Glen Canyon Dam rates analysis data was developed by Argonne National Laboratory. Information and modeling assumptions for the rates analysis can be found in *Post-2026 Environmental Impact Statement Rate Analysis for the Colorado River Storage Project* (Yu et al. 2025).

Impact Indicators

- Lake Powell and Lake Mead Reservoir elevations
- Firm energy capacity (MW)
- Energy generation (MWh)
- Spillway releases
- Electricity rates and the market value of electricity

Issue 1: How do the alternatives impact the frequency at which reservoir elevations drop below the minimum power pool at Lake Powell and Lake Mead?

The minimum power pool is the lowest reservoir elevation at which a hydropower plant can produce power. The potential frequency at which reservoir elevations drop below minimum power pool was measured by calculating the percentage of futures in which the Lake Powell and Lake Mead reservoirs achieve desirable elevations of at least 3,490 feet and 950 feet, respectively (refer to **Figure TA 15-9** and **Figure TA 15-11** in **TA 15**, Dams and Electrical Power Resources), and by using vulnerability figures that display conditions that could cause Lake Powell and Lake Mead to drop below the desirable elevations of 3,450 feet and 950 feet, respectively (refer to **Figure TA 15-10** and **Figure TA 15-12** in **TA 15**).

The Maximum Operational Flexibility Alternative would provide the greatest degree of power pool robustness for both Lake Powell and Lake Mead. For Lake Powell, the second-highest level of robustness would occur under the Enhanced Coordination Alternative, and the least amount of robustness would be provided by the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches). Conversely, for Lake Mead, the second-highest level of robustness would be provided by the Supply Driven Alternative (LB Pro Rata approach), followed by the Enhanced Coordination Alternative. For Lake Mead elevation robustness, the least robust alternative is the No Action Alternative. From the perspective of keeping the elevations of both reservoirs above a preferred threshold during the driest of hydrologic conditions, the Maximum Operational Flexibility and Enhanced Coordination Alternatives would provide the most robust outcomes for Lake Powell, and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and the No Action Alternative would provide the least robust outcomes. For Lake Mead, the Maximum Operational Flexibility Alternative, Supply Driven Alternative (LB Pro Rata approach), and Enhanced Coordination Alternative would provide the most robustness, and the No Action Alternative would provide the least robustness.

Issue 2: How would the alternatives impact the firm capacity of the Glen Canyon Dam and Hoover Dam power plants?

Firm energy capacity is the reliable, guaranteed amount of power output from a power plant that accounts for operational constraints such as water releases and ramp rates. Firm capacity is measured in MW. This section considers how the different alternatives affect the annual firm capacity of the hydropower plants at the Glen Canyon Dam and Hoover Dam in August. The analysis of capacity utilizes boxplots that display the firm capacity of the Glen Canyon and Hoover Dam for a 3-year period across 5 different potential flow categories at Lees Ferry using August as the flow month (refer to **Figure TA 15-14** and **Figure TA 15-15** in **TA 15**, Dams and Electrical Power Resources).

For Glen Canyon Dam, the firm capacity would be highest in the Average Flow Category (12.0–14.0 maf) under the Enhanced Coordination Alternative, followed by the CCS Comparative Baseline, and would be lowest under the No Action Alternative. Under the other action alternatives, in the Average Flow Category there would be a similar capacity of between 675 and 725 MW. In the Critically Dry Flow Category (4.46–10.0 maf), the No Action Alternative, Basic Coordination Alternative, Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), and CCS Comparative Baseline would show a wide range of interquartile values, with all having the potential for capacity to drop to 0 MW. In the Critically Dry Flow Category, the capacity for every alternative and the CCS Comparative Baseline would be below 725 MW.

For Hoover Dam, in the Average Flow Category (12.0–14.0 maf), the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), Enhanced Coordination Alternative, and Maximum Operational Flexibility Alternative would yield the highest capacity, each exceeding 1,250 MW. The CCS Comparative Baseline, No Action Alternative, and Basic Coordination Alternative all would have wide interquartile ranges. The No Action Alternative would result in a substantially lower capacity in the Average Flow Category. In the Dry Flow Category (10.0–12.0 maf), the Supply Driven Alternative (LB Pro Rata approach) would provide the highest capacity and the smallest interquartile range. All other action alternatives would have wide interquartile ranges and varying capacity in the Dry Flow Category. The No Action Alternative and the CCS Comparative Baseline would have substantially lower capacity in the Dry Flow Category. In the Critically Dry Flow Category (4.46–10.0 maf), the Supply Driven Alternative (LB Pro Rata approach) would have the highest capacity but, like the other action alternatives, would have a wide interquartile range under the Critically Dry Flow Category. Under the Critically Dry Flow Category, the Supply Driven Alternative (LB Priority approach) and Basic Coordination Alternative would have the potential to drop to 0 MW. The CCS Comparative Baseline and the No Action Alternative would produce the lowest capacity in the Critically Dry Flow Category, and they both would have the potential to drop to 0 MW.

Issue 3: How would the alternatives impact the energy generation of the Glen Canyon Dam, Hoover Dam, Davis Dam, and Parker Dam power plants?

Energy generation is the amount of energy created over a certain period, measured in MWh. Energy generation is dependent on reservoir head and water release volume. The model inputs used to develop the boxplot figures in this analysis simulated releases and lake reservoir elevations to calculate estimated energy generation for the Glen Canyon Dam, Hoover Dam, Davis Dam, and Parker Dam power plants. The boxplots show the power output of the dams for five potential flows at Lees Ferry, using August as the flow month. Please refer to **Figure TA 15-16**, **Figure TA 15-17**, **Figure TA 15-18**, and **Figure TA 15-19** in **TA 15**, Dams and Electrical Power Resources.

For the Glen Canyon Dam power plant, all alternatives would perform similarly in the Average Flow Category (12.0–14.0 maf; refer to **Figure TA 15-16** in **TA 15**, Dams and Electrical Power Resources). In the Critically Dry Flow Category (4.46–10.0 maf), the Enhanced Coordination and Maximum Operational Flexibility Alternatives would have the highest power generation and the smallest interquartile range. The Basic Coordination Alternative and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), along with the CCS Comparative Baseline, would have larger interquartile ranges and substantially lower levels of power generation.

For the Hoover Dam power plant (as shown in **Figure TA 15-17** in **TA 15**, Dams and Electrical Resources), in the Average Flow Category (12.0–14.0 maf), energy generation would be similar across all action alternatives, with relatively small interquartile ranges. The No Action Alternative would have the greatest interquartile range and the lowest level of power generation. In the Dry Flow Category (10.0–12.0 maf) and Critically Dry Flow Category (4.46–10.0 maf), the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in the highest generation, followed by the Maximum Operational Flexibility and the Basic Coordination Alternatives. In the Critically Dry Flow Category, the No Action Alternative would produce the least amount of power and, like the CCS Comparative Baseline and the Basic Coordination Alternative, would have the potential to drop to 0.0 MWh.

For the Davis Dam power plant (as shown in **Figure TA 15-18** in **TA 15**, Dams and Electrical Power Resources), in the Average Flow Category (12.0–14.0 maf), the No Action Alternative and the CCS Comparative Baseline would result in the highest generation. Under the Dry Flow Category (10.0–12.0 maf), the No Action and Basic Coordination Alternatives, along with the CCS Comparative Baseline, would result in the highest generation. The Enhanced Coordination Alternative would result in the lowest generation. In the Critically Dry Flow Category (4.46–10.0 maf), the Basic Coordination Alternative and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in the highest generation. The No Action Alternative and CCS Comparative Baseline both would have lower generation and higher interquartile ranges.

For the Parker Dam power plant (as shown in **Figure TA 15-19** in **TA 15**, Dams and Electrical Power Resources), in the Average Flow Category (12.0–14.0 maf), the Enhanced Coordination Alternative and Supply Driven Alternative (LB Pro Rata approach) would have low generation and high interquartile ranges. The remaining alternatives, including the CCS Comparative Baseline, would have very small interquartile ranges and produce similar amounts of power (40 MWh). The same trends are seen in the Dry Flow Category (10.0–12.0 maf), with the Enhanced Coordination Alternative and Supply Driven Alternative (LB Pro Rata approach) producing the lowest levels of power. In the Critically Dry Flow Category (4.46–10.0 maf), the Basic Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (LB Priority approach) would result in the highest levels of power with the lowest interquartile ranges. The Enhanced Coordination Alternative would have the lowest generation, followed by the No Action Alternative, the Supply Driven Alternative (LB Pro Rata approach), and the CCS Comparative Baseline, in the Critically Dry Flow Category.

Issue 4: How would the alternatives impact spillway infrastructure and life safety?

Spillway infrastructure and life safety are affected by the frequency of high reservoir elevations, which vary greatly between the alternatives. High reservoir elevations for extended durations pose a risk to spillway infrastructure. This analysis compares the various action alternatives with the No Action Alternative and the CCS Comparative Baseline for the following metrics:

- Lake Powell pool elevations
- Lake Mead pool elevations

From a spillway condition and life safety perspective, keeping the reservoir water level below the spillway crest is essential for dam and public safety. Minimizing spillway use preserves the water supply, maintains flood storage capacity, and reduces wear and tear on spillway infrastructure. Maintaining lower reservoir levels allows inflow to be routed through controlled outlets, respond to spring runoff, and protect life safety downstream.

At Lake Powell, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be the most robust at maintaining elevations below 3,684 feet and 3,700 feet (see **Figure TA 15-20** and **Figure TA 15-22** in **TA 15**, Dams and Electrical Power Resources). The No Action Alternative would be the least robust at maintaining elevations below 3,684 feet. The Basic Coordination Alternative and CCS Comparative Baseline would be the second most robust at maintaining elevations below 3,700 feet. The No Action, Enhanced Coordination, and Maximum Operational Flexibility Alternatives would be the least robust at maintaining elevations below 3,700 feet.

At Lake Mead, the No Action and Basic Coordination Alternatives, along with the CCS Comparative Baseline, would be the most robust at maintaining elevations below 1,205.4 feet, 1,219 feet, and 1,226.9 feet. Refer to **Figure TA 15-26**, **Figure TA 15-28**, and **Figure TA 15-30** in **TA 15**, Dams and Electrical Power Resources. The Enhanced Coordination and Maximum Operational Flexibility Alternatives would be the second most robust at maintaining reservoir levels below these elevations. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be the least robust at maintaining reservoir levels below these elevations.

Issue 5: How would changes in energy capacity and energy generation impact the electricity rates and the market value of the electricity?

Glen Canyon Dam

Argonne National Laboratories and WAPA analyzed the impacts of the alternatives on the projected electricity rates and the market value of electricity from Glen Canyon Dam. Their report (Yu et al. 2025), which is incorporated here by reference, documents the modeling framework and key methodologies used to identify these findings. They found that Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) are associated with higher electricity production, lower projected rate trajectories, and reduced long-term market values. They found that under wet or average hydrologic conditions, the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would lead to similar or slightly better results than those under the other alternatives. Under dry hydrologic conditions, the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in substantially smaller rate increases and less frequent rate adjustments. In addition, the report documents their findings that under favorable hydrologic conditions, the alternatives would result in similar market values. The analysis shows that under conditions of water scarcity, the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in substantially higher values of electricity generated at Glen Canyon Dam.

DMDU analysis of electricity rates and the market value of the electricity generated at Glen Canyon Dam are being developed and will be included in the Final EIS.

Hoover Dam

Impacts on electricity rates and the market value of the electricity generated at Hoover Dam are being developed and will be included in the Final EIS.

Summary Comparison of Alternatives

No Action

For Glen Canyon Dam, the No Action Alternative provides the lowest level of power pool robustness of the alternatives analyzed and is also the least robust at staying below critical spillway infrastructure and life safety elevations. Firm capacity and power generation under the No Action Alternative would be among the lowest of the alternatives analyzed.

For Hoover Dam, the No Action Alternative would result in the lowest power pool robustness, but it is the most robust alternative relative to spillway infrastructure and life safety. As with Glen Canyon Dam, the No Action Alternative would result in one of the lowest amounts of power generation. For Davis Dam and Parker Dam, the No Action Alternative would perform relatively well across most flow categories, but under dry conditions, it could result in low energy generation.

Basic Coordination

For Glen Canyon Dam, the Basic Coordination Alternative would be relatively robust in maintaining minimum power pool elevations and would provide a high level of firm capacity, except under the driest hydrologic flow category. The Basic Coordination Alternative would be moderately robust in terms of spillway infrastructure and life safety. This alternative would produce more energy than the No Action Alternative and would have power production similar to that of the Supply Driven Alternative. The Basic Coordination Alternative would provide less power production than the Enhanced Coordination and Maximum Operational Flexibility Alternatives, which would provide the highest levels of energy production for Glen Canyon Dam.

For Hoover Dam, this alternative would have the third-lowest level of power pool robustness and the second-highest level of robustness relative to spillway infrastructure and life safety. This alternative would produce less power than the other action alternatives and would have a very high interquartile range in power production across the Average to Critically Dry Flow Categories.

For both Davis Dam and Parker Dam, this alternative would produce one of the highest levels of power among the action alternatives in all but the highest flow scenario, where the Supply Driven Alternative would produce the highest amounts of power.

Enhanced Coordination

For Glen Canyon Dam, the Enhanced Coordination Alternative would be the second most robust at maintaining minimum power pool elevations and would have a moderate level of spillway infrastructure and safety robustness, a high level of power capacity, and a high level of power production under all flow categories.

For Hoover Dam, this alternative would provide the third-highest level of power pool robustness after the Supply Driven Alternative and the Maximum Operational Flexibility Alternative, and a high level of spillway infrastructure and life safety robustness. This alternative would provide lower power capacity and power production than the Maximum Operational Flexibility Alternative and Supply Driven Alternative, which would produce the most capacity and the highest levels of power under most flow categories for Hoover Dam.

For Davis Dam, power production under this alternative would be moderate under high flows and low under low flows. For Parker Dam, this alternative would produce the least amount of power among all alternatives under the Average Flow to Critically Dry Flow Categories.

Maximum Operational Flexibility

For Glen Canyon Dam, the Maximum Operational Flexibility Alternative would provide the highest power pool robustness and low to moderate robustness relative to spillway infrastructure and safety robustness. Along with the Enhanced Coordination Alternative, this alternative would yield the highest power generation of the alternatives across most flow categories.

For Hoover Dam, this alternative would provide the highest power pool robustness and a high level of robustness relative to spillway infrastructure and safety. This alternative would provide the second-highest level of power capacity and power production after the Supply Driven Alternative under most flow conditions.

For Davis Dam and Parker Dam, power production would be relatively low under this alternative.

Supply Driven Alternative

For Glen Canyon Dam, the Supply Driven Alternative would provide the second-lowest level of power pool robustness and a high level of robustness relative to spillway infrastructure and safety. For power capacity, the Supply Driven Alternative would provide moderate firm capacity for Glen Canyon Dam. This alternative would provide a moderate level of power production when compared with the Enhanced Coordination and Maximum Operational Flexibility Alternatives, which would provide higher levels of power under all flow categories except the wettest.

For Hoover Dam, the Supply Driven Alternative would provide the highest levels of power pool robustness. The Supply Driven Alternative would provide a moderate level of robustness for spillway infrastructure and safety. From a power production perspective, this alternative would provide the highest level of power production across all of the flow categories.

For Davis Dam, the Supply Driven Alternative would provide generation in the middle of the range when compared with the other alternatives, in most flow categories. For Parker Dam, the Supply Driven Alternative (LB Priority approach) would result in generation that is comparable to multiple alternatives under all but the high flow scenario, where it would be among the highest. In all but the Wet Flow Category (16–31.11 maf), the Supply Driven Alternative (LB Pro Rata approach) would produce one of the lowest amounts of power of all the alternatives.

3.16 Socioeconomics

3.16.1 Affected Environment

This section briefly discusses key current conditions of economic indicators—such as employment, labor income, and unemployment rates—as well as social and nonmarket values. For additional details on these current conditions, please reference **Section TA 16.1**, Affected Environment, in **TA 16**, Socioeconomics. For overall demographic information, such as population and race and ethnicity data, please reference **Section TA 16.1.4**, Demographics, and **Section TA 17.1**, Affected Environment, in **TA 17**, Population and Land Use. For information on tribal populations and interests, please reference **TA 13**, Tribal Resources**.**

The socioeconomic analysis area includes counties in Arizona, California, Nevada, and Utah (see **Map TA 16-1**). The Arizona analysis area consists of Apache, Coconino, Gila, Graham, La Paz, Maricopa, Mohave, Navajo, Pima, Pinal, Yavapai, and Yuma Counties. The California analysis area consists of Imperial, Los Angeles, Orange, Riverside, San Bernardino, and San Diego Counties. The Nevada analysis area consists solely of Clark County. The Utah analysis area consists of Garfield, Kane, and San Juan Counties. These analysis areas include counties that are directly adjacent to Lake Powell, Lake Mead, or the mainstream Colorado River; counties that receive water from the Colorado River and in which impacts from Colorado River shortages would likely occur; counties that have ties to recreation-related economic activity on the Colorado River; and counties where tribal reservations affected by Colorado River shortages are located and that have ties to tribal water rights settlements involving CAP water and non-CAP Colorado River water delivered through the CAP.[15]

The analysis of impacts on economic and social conditions due to changes in agricultural production includes Arizona, California, and Nevada. The analysis of economic impacts from changes in recreation use includes Arizona, California, Nevada, and Utah. The impact analysis on ecosystem services and nonmarket values includes Arizona, California, Nevada, and Utah.

Baseline Economic Conditions

The following section provides an overview of county-level data for baseline economic conditions, including data on employment, labor income, unemployment rates, poverty, and the market value of agricultural production in the analysis areas. The county-level data do not distinguish between the

[15] See **Section 1.5.1**, Geographic Scope of the Proposed Federal Action and Affected Regions and Interests, of this Draft EIS for more information on the geographic scope that would be affected by the alternatives analyzed.

water source(s)—which may include sources other than, or blended with, the mainstream Colorado River and CAP—that were used in support of the economic conditions presented.

Arizona

In 2022, total employment in the analysis area counties (about 4.2 million) represented approximately 98.1 percent of total employment in Arizona. Farm employment in the 12 counties totaled almost 26,000 jobs in 2022 (about 0.6 percent of total analysis area employment). While total employment in the analysis area increased from 2010 employment levels by about 36 percent, farm employment decreased during the same time period by about 2 percent (see **Table TA 16-1** and **Table TA 16-2**). Employment in the arts, entertainment, and recreation sector totaled approximately 84,000 jobs (or 2.0 percent of the total employment in the analysis area) in 2022, which was an increase of about 27 percent from the number of jobs in 2010.

In 2022, the total market value of agricultural products sold in the Arizona analysis area contributed $4.8 billion to Arizona's economy, which was about 91 percent of the market value of agricultural products sold in the state. Across Maricopa, Pima, and Pinal Counties, the market value of crops sold in 2022 ranged from about $87.1 million in Pima County to about $742.6 million in Maricopa County (USDA 2024; see **Table TA 16-5**). In 2022, the Maricopa, Pima, and Pinal Counties accounted for approximately 55 percent of Arizona's harvested acres of hay and haylage crops, 65 percent of the state's harvested acreage of cotton, and 44 percent of the harvested wheat acreage. The three western Arizona counties that are located along the Colorado River—Mohave, La Paz, and Yuma Counties—accounted for approximately 33 percent of the statewide harvested hay and haylage acreage, 78 percent of the harvested acres of vegetable crops, and 53 percent of the harvested wheat acres in 2022. Yuma County alone accounted for 77 percent of the state's total harvested acres of vegetable crops (USDA 2024). Additional information on irrigated agricultural acreage within the analysis area is provided in **TA 17**, Population and Land Use.

California

In 2022, total employment in the analysis area counties (about 13.9 million) represented approximately 55 percent of total employment in California. Farm employment in the six counties totaled almost 31,000 jobs in 2022 (about 0.2 percent of the total analysis area employment). Farm employment made up a larger percentage of total employment in Imperial County than the rest of the counties in the analysis area, with 4.7 percent of total employment coming from the farm sector in Imperial County (BEA 2024). While total employment in the analysis area increased from 2010 employment levels by about 30 percent, farm employment decreased by about 9 percent during the same time period (see **Table TA 16-6** and **Table TA 16-7**).

In 2022, the total market value of agricultural products sold in the California analysis area contributed $6.1 billion to California's economy. The market value of crops sold in the analysis area was about $4.7 billion, ranging from about $69.5 million in Orange County to about $2.2 billion in Imperial County (USDA 2024; see **Table TA 16-10**). In 2022, the California analysis area counties accounted for approximately 30 percent of California's harvested acres of hay and haylage crops, 16 percent of the state's harvested acreage of vegetables, and 35 percent of the harvested wheat acreage (USDA 2024).

Nevada

In 2022, total employment in Clark County (about 1.5 million) represented approximately 74 percent of the total employment in Nevada. In 2022, employment in the arts, entertainment, and recreation sector totaled almost 47,000 jobs, or 3.1 percent of the total employment in the county. Farm employment represented less than 0.1 percent of total employment, with a little more than 400 jobs (see **Table TA 16-11**).

Approximately 8.4 percent of Nevada's land area in 2022 was used for agricultural purposes (on cropland, pastureland, woodland, or other; USDA 2024). In 2022, the market value of agricultural products sold in Nevada contributed nearly $1 billion to the statewide economy.

Utah

In 2022, total employment in the analysis area counties (about 17,000) represented approximately 1.0 percent of the total employment in Utah. In 2022, employment in the arts, entertainment, and recreation sector totaled approximately 400 jobs (or 2.4 percent of the total employment in the analysis area) and represented 6.0 percent of employment in Kane County (see **Table TA 16-14**).

Economic Contributions from Recreational Use

Total economic output for lake-based recreation in the analysis area was $358 million from Lake Mead NRA and $670 million from Glen Canyon NRA, and the total economic output for river-based recreation was $1,022 million in Grand Canyon National Park (GCNP; see **Table TA 16-17** and **Table TA 16-18**).[16] These amounts account for total visitor spending, including spending by local and nonlocal visitors. Spending by nonlocal visitors represents an influx of dollars from outside the local economy. In addition, nonlocal visitors typically have higher levels of spending on food, lodging, and other activities on a per-trip basis. Glen Canyon NRA, Lake Mead NRA, and GCNP had 96.3 percent, 88.3 percent, and 98.8 percent of spending from nonlocal visitors, respectively (Flyr and Koontz 2024). In 2023, Glen Canyon NRA recreation spending supported 6,300 jobs, Lake Mead NRA recreation supported 3,131 jobs, and GCNP recreation supported 10,064 jobs (Flyr and Koontz 2024; see **Table TA 16-19** and **Table TA 16-20**).

In addition to general recreation sector contributions, visitor use supports concessionaires, including those associated with water-based recreation, such as commercial river trips. In GCNP, commercial river trips hosted about 17,000 passengers in 2023 (a slight decrease from about 20,000 passengers in 2022 and 21,000 passengers in 2021). From these river trips, river concessionaires contributed $63.6 million in 2023 in gross revenue (a decrease from $66.4 million in 2021, in 2023 dollars), representing 29 percent of the total concessionaire revenue at GCNP. River concessionaire franchise fees paid to the NPS in 2023 totaled $6.25 million, of which 80 percent stays at GCNP.[17]

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[16] Economic output for recreation is the total estimated value of the production of goods and services supported by visitors' spending, including the direct, indirect, and induced impacts. Direct impacts occur when businesses sell goods and services to area visitors. Indirect impacts are economic activity supported when businesses purchase supplies and services from other local businesses. Induced impacts occur when employees use their income to purchase goods and services in the local economy.

[17] Laurie Dyer, NPS supervisory concessions management specialist in the Commercial Services Division at GCNP, personal communication provided on September 27, 2024.

NWRs also support economic contributions through expenditures from recreational visitors, such as entrance fees, lodging near the refuges, and purchases from local businesses for items to pursue their recreational experience. In 2017, the Imperial NWR supported about $11.1 million in total economic output (see **Table TA 16-21**).

For additional information on recreation and levels of use in the analysis area, please reference **TA 14**, Recreation**.**

Social and Nonmarket Values

Nonmarket values refer to resource benefits that are not captured in market transactions or traditional economic measures. Along the Colorado River, these values include the enjoyment of natural scenery, opportunities for recreation and solitude, preservation of landscapes, and the symbolic and ecological importance of the river itself. Such values are important for understanding how river operations affect people's experiences, sense of place, and well-being, even when no direct economic exchange is involved. Place-based communities—such as gateway communities—and non-place-based communities—such as individuals who may never visit but who value the river—derive nonmarket values from the Colorado River, including cultural identity, recreation quality, aesthetics, and existence values. These values often differ by type of community as well as an individual's beliefs. Understanding these values provides important context for assessing potential changes in access and the quality of nonmarket and social values under the post-2026 operational alternatives. For additional details on these social and nonmarket values, please reference **Section TA 16.1**, Affected Environment.

3.16.2 Environmental Consequences

Methodology

Agriculture

Below is a brief summary of the methodology used to analyze economic conditions from changes in agricultural production as a result of a reduction of irrigation water. For additional details on the methodology, please reference **Section TA 16.2.1**, Methodology.

Based on the SAMs and ADMs (see **Appendix C**, Shortage Allocation Model and the Alternative Distribution Model Documentation), Reclamation modeled the change in agricultural revenue from fallowed crops for each county in the impact analysis area due to water shortages at a variety of shortage levels across each alternative and the comparative baseline.

Forgone agricultural revenue from fallowed crops was estimated by multiplying the county-level revenue per acre by the number of acres reduced (or fallowed) for each crop. The county-level revenue was calculated based on the most recent available data on yields and prices. The number of acres reduced for each crop was modeled based on a determined order in which crops are fallowed (which was based on the crops' profitability and water use), the level of shortages and available water for each county, and the most recent available data on acres harvested. For data that were not available for specific crops grown in the county, estimated data were used based on statewide averages, data from nearby counties, or averages from nearby states or regions for the same or similar crops.

Irrigated crops in the analysis area that were analyzed include field crops, vegetables, and fruit and nut trees and vines, separated out into eight agricultural crop group types that would be affected by the Colorado River shortages and that made up at least approximately 1 percent of a county's harvested acres. The eight crop groups were alfalfa, cotton, crucifer vegetables, field grains, fruit and tree nuts and vines, other hay and haylage, small grains, and small vegetables.

Impacts on economic conditions, such as jobs and income, from changes in agricultural production were analyzed using the IMPLAN input-output economic model. IMPLAN is a regional economic model that describes the flow of money, goods, and services from producers to intermediate and final consumers using a series of economic multipliers. The IMPLAN model provides annual average estimates of how a direct change in economic spending (such as through reduced agricultural revenues) would ripple through the broader economy and other industries. Prior to running the model, cost data were converted to a consistent dollar year (2025). Unless stated otherwise, monetary values are reported in the year 2025 dollars.

Recreation

This analysis evaluates how changes in reservoir elevations and river flows may affect recreational use and related economic contributions. The approach integrates visitor use data, spending information, and economic modeling tools to characterize potential changes in both the recreational experience and the regional economy.

For lake-based recreation, the analysis uses visitor statistics from the NPS and Reclamation to estimate changes in visitation levels under different hydrologic conditions. Visitor days are categorized by visitor type, including local and nonlocal trips. Each visit type is linked to an established spending profile that reflects patterns in lodging, food, transportation, recreational services, and other trip-related expenditures. Total spending estimates are then used in a regional economic modeling framework (IMPLAN) to assess potential changes in jobs, labor income, value added, and overall economic output resulting from changes in recreational use.

For river-based recreation, the analysis also evaluates net economic value, which measures the benefits that recreationists receive beyond their direct expenditures. Consistent with the approach used in the 2024 LTEMP Final SEIS, past survey research, including that by Gaston et al. (2015), informs models that relate the willingness to pay for boating and angling experiences to the river's flow conditions. These models estimate how changes in hydrologic patterns may affect the value of specific recreational experiences in Glen Canyon and Grand Canyon.

Together, these components provide a qualitative and quantitative framework for assessing how operational changes influence recreational access, the quality of the experience, and economic contributions. Additional methodological detail, including data sources, assumptions, and model parameters, is provided in **TA 16**, Socioeconomics.

Ecosystem Services and Nonmarket Values

The analysis of ecosystem services and nonmarket values uses a qualitative framework to evaluate how changes in Colorado River operations may affect benefits that are not reflected in market transactions but that contribute to community well-being, cultural identity, and the recreational experience. These include values such as scenic quality, sense of place, ecological integrity, and cultural connections to the river corridor. The analysis draws on scoping input, existing literature, and information from other resource sections to understand how various groups interact with and derive value from the Colorado River system. Additional details on information sources, assumptions, and community context are provided in **TA 16**, Socioeconomics.

Impact Analysis Area

Agriculture

The quantitative impact analysis was conducted for the following counties: La Paz, Maricopa, Mohave, Pima, Pinal, and Yuma Counties in Arizona; Imperial, Riverside, and San Bernardino Counties in California; and Clark County in Nevada. The impact analysis area for the qualitative discussions extends to the surrounding communities and tribal reservations.

Recreation

The analysis area is consistent with the general socioeconomic study area defined in **Section 3.1**, Introduction. This includes major recreation hubs, gateway communities, and rural areas where economies rely heavily on river- and reservoir-based recreation. Specifically, the recreation impact analysis area encompasses three primary NPS units: Lake Mead NRA, Glen Canyon NRA, and GCNP.

Ecosystem Services and Nonmarket Values

The analysis area for social and nonmarket values is the Colorado River corridor from Lake Powell to the SIB, consistent with the overall socioeconomic study area. Consideration is focused on, but not limited to, geographic boundaries; this is because non-place-based communities also hold nonmarket values. The area, therefore, includes both local communities along the river and the broader public for whom the river holds symbolic, ecological, or recreational importance.

Assumptions

Agriculture

Below is a list of the key assumptions used in the analysis. For additional details on assumptions, please reference **Section TA 16.2.1**, Methodology.

- Farmers would fallow irrigated crops in response to water shortages rather than using other water sources or switching to more profitable or less water-intensive crops. The assumption that farmers would fallow rather than switch crops is based on the investments and institutional knowledge that have been made in plants, supply chains/relationships, and/or machinery that create barriers for changing crops. Reclamation understands that there could be farmers who are able to switch crops, rather than fallow; however, for the purpose of this analysis, this assumption provides a bound to the analysis and any changes in this assumption would likely result in less impacts than discussed below. Impacts on economic conditions due to the use of groundwater to replace the estimated water shortage are discussed qualitatively.
- Crops have a constant profitability per acre of land and per acre-foot of water.
- Estimated shortages in the agricultural sector are based on the SAMs and ADMs (**Appendix C**, Shortage Allocation Model and Alternative Distribution Model

Documentation). Shortages to individual entitlement holders are measured in terms of consumptive use for a common basis of comparison with state apportionments and volumes of total shortage. Impacts from shortages on water consumption expansion opportunities for irrigation entitlement holders with current consumptive use that is less than their entitlement are discussed qualitatively.

Recreation

- Lake-based recreational spending per visitor trip is based on the most recent NPS Visitor Spending Profiles.
- IMPLAN results represent regional impacts, including direct, indirect, and induced economic activity associated with lake-based recreation.
- Recreational spending per trip for anglers and whitewater rafting (adjusted for inflation) would follow results from willingness-to-pay surveys (Gaston et al. 2015) with variation based on river flows.

Ecosystem Services and Nonmarket Values

- Nonmarket values are not directly quantifiable through market-based indicators; however, they can be described qualitatively based on existing studies, stakeholder input, and related resource analyses.
- Changes in nonmarket values are assumed to be closely linked to conditions evaluated in other TAs, such as the TAs for recreation, population and land use, cultural resources, and visual resources.
- Changing hydrology may influence how these values are perceived, particularly where access, scenic character, or ecological conditions are affected.

Impact Indicators

Agriculture

- Change in acres of fallowed cropland
- Change in production value or revenue associated with fallowed cropland
- Change in jobs and income associated with agriculture
- Change in nonmarket values and social conditions associated with changes in agriculture

Recreation

- Changes in direct recreational visitor spending across the affected NPS units and recreation sites
- Changes in regional employment, labor income, value added, and total economic output from lake-based recreation-related activities
- Impacts on recreational value associated with river-based boating and angling
- Impacts on commercial outfitters, concessionaires, and permittees, especially in areas dependent on rafting, boating, and guided recreation

Ecosystem Services and Nonmarket Values

- Changes in the availability or quality of recreational opportunities not captured by direct spending
- Changes in the existence and symbolic values of the river due to shifts in the scenic character or ecological conditions

Issue 1: How would the anticipated water shortages affect the economic contributions and social conditions from agriculture?

Under all alternatives and the CCS Comparative Baseline, anticipated shortages would result in increases in acres of fallowed cropland and agricultural production loss, and the modeled agricultural production loss would result in impacts on the associated jobs, income, and total economic output. Additionally, under the alternatives and the CCS Comparative Baseline, water shortages would likely lead to changes in the quality and access to nonmarket values and social conditions associated with changes in agriculture (Curtis et al. 2023). These values that could be affected by water shortages include the way of life of individuals throughout the surrounding communities, how individuals perceive their sense of place, the provisions and food that the Colorado River supports, access to affordable health care, and access to cultural, traditional, and spiritual uses. The magnitude of impacts on economic, nonmarket, and social conditions varies by region, irrigation and tribal entitlement holder, and the alternatives and the CCS Comparative Baseline, as discussed below. For additional details and the figures with modeling results, please reference **Section TA 16.2.2**, Environmental Consequences, Issue 1.

For non-tribal agriculture entitlement holders in Arizona, the greatest impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the Maximum Operational Flexibility Alternative (during a shortage of 4.0 maf), with an annual estimated reduction of almost 1,000 jobs, about $46.8 million in labor income, and $207.6 million in total economic output. The lowest impacts on economic conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the No Action Alternative (during a shortage of 0.6 maf), for non-tribal agriculture entitlement holders in Arizona; under this alternative, there would be an annual estimated reduction of about 13 jobs, $0.6 million in labor income, and $2.8 million in total economic output.

For non-tribal agriculture entitlement holders in California, the largest impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the Enhanced Coordination Alternative (during a shortage of 3.0 maf), with an annual estimated reduction of about $1.0 billion in total economic output. However, the biggest impacts on jobs and labor income during a maximum shortage would occur under the Maximum Operational Flexibility Alternative, with an annual estimated reduction of almost 5,000 jobs and about $336.3 million in labor income. For non-tribal agriculture entitlement holders in California, there would be no impacts on fallowed lands, the market value of crops, and economic conditions during a maximum shortage under the No Action Alternative (during a shortage of 0.6 maf) and the Basic Coordination Alternative (during a shortage of 1.5 maf).

For tribal agriculture entitlement holders in Arizona, during a maximum shortage, the highest level of impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops would occur under the Maximum Operational Flexibility Alternative (during a shortage of 4.0 maf), with an annual estimated reduction of about 1,000 jobs, about $57.1 million in labor income, and $199.2 million in total economic output. The lowest impacts on economic and social conditions during a maximum shortage would occur under the No Action Alternative (during a shortage of 0.6 maf), for tribal agriculture entitlement holders in Arizona, with an annual estimated reduction of about 135 jobs, $10.7 million in labor income, and $34.8 million in total economic output.

For California and Nevada tribal entitlement holders, the only impacts on fallowed lands, the market value of crops, and economic conditions are expected to occur under the Enhanced Coordination Alternative and Supply Driven Alternative (LB Pro Rata approach). The greatest impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the Enhanced Coordination Alternative (during a shortage of 3.0 maf), with an annual estimated reduction of about 63 jobs, $3.9 million in labor income, and $15.9 million in total economic output for tribal entitlement holders in California; for Nevada, there would be an estimated reduction of about 13 jobs, $0.1 million in labor income, and $0.9 million in total economic output for tribal entitlement holders.

Long-term and deep Colorado River water shortages could result in further impacts on the economic contributions to entitlement holders that have unused water entitlement above their current consumptive use. During long-term shortages, these irrigation entitlement holders with current consumptive use that is less than their entitlement could experience further impacts on economic contributions through the loss of future opportunities to expand their water consumption, through future developments or leasing water to other end users. These future impacts could reduce economic contributions associated with either future expansion of crop production or future opportunities to lease water.

If farmers and agricultural producers decide to use irrigation water from other sources—such as other surface water or groundwater sources—instead of fallowing agricultural acreages, the impacts on the economic and social conditions, discussed above, are likely to be lessened in the short term. However, in the event of long-term shortages, if the sustained demand for groundwater results in a reduction in supply from the aquifers, there would likely be increased impacts on economic and social conditions. Additionally, the reliance on more pumped groundwater to offset delivery shortages can lead to substantial additional pumping costs, particularly for electricity, which can affect economic conditions. These impacts on economic and social conditions would affect tribal and non-tribal entitlement holders in California, Nevada, and Arizona, as well as farmers and tribes who rely solely on groundwater for irrigation and domestic needs.

Issue 2: How would operational changes affect economic contributions and the value associated with lake-based and river-based recreation?

Recreation along the Colorado River is a key part of several local economies, supporting thousands of jobs and generating revenue through visitor spending. Lake-based recreation at Glen Canyon NRA and Lake Mead NRA, combined with river-based activities in GCNP, currently contribute approximately 12,000 jobs and $1.6 billion in annual economic output (Flyr and Koontz 2024). These benefits extend beyond direct spending on lodging, food, and equipment and include indirect and induced impacts throughout gateway communities. Stable reservoir elevations and predictable river flows are essential for maintaining these contributions.

Operational changes under the proposed alternatives would influence these conditions in different ways. The alternatives that maintain higher and more consistent water levels would preserve boating access, marina operations, and shoreline recreational opportunities. This stability would support continued visitation and minimize disruptions to businesses dependent on tourism. Conversely, the alternatives that result in greater variability in lake elevations and river flows would affect recreational quality and access and related levels of contributions.

The Supply Driven Alternative poses the greatest risk to recreation-based economies relying on economic contributions from reservoir-based recreation in Lake Powell, while the CCS Comparative Baseline and the No Action Alternative have the least robust modeled performance for supporting recreational opportunities and spending associated with Lake Mead recreation. In contrast, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in more consistent reservoir levels at Lake Powell to support recreation, and the Supply Driven Alternative would support the greatest level of contributions from recreation in Lake Mead.

However, under all alternatives, access to launch facilities and safe navigation routes for Lake Powell and navigational challenges in Lake Mead would continue to impact lake-based recreational opportunities and the associated spending. As a result, outfitters and concessionaires operating in these areas would face increased uncertainty, affecting employment and revenue streams under all alternatives. Research indicates that declines in lake elevation can reduce visitation by more than 25 percent, amplifying economic losses for local communities (Johnson et al. 2016). Lake Mead would experience similar constraints, with boating access severely limited during extended drought periods.

River-based recreation is also vulnerable to operational changes. Activities such as angling in Glen Canyon and whitewater rafting in Grand Canyon depend on stable flows to ensure safety and trip quality. Reduced flows shorten rafting seasons and diminish the overall experience, leading to lower recreational value and reduced demand for outfitter services and the associated hospitality sectors. The Basic Coordination Alternative would provide the most support for continued or increased economic value associated with boating and angling and the related economic contributions. The Enhanced Coordination Alternative would be the least robust at maintaining or exceeding the minimum desired daytime flows to support boating in Grand Canyon; it also would result in the greatest potential for a reduction in the recreational value for whitewater rafting and angling, as well as the associated regional economic contributions associated with these uses. Impacts would be most pronounced under dry conditions.

Economic impacts extend beyond direct visitor spending. Gateway communities, often small and rural, rely heavily on tourism-related income to sustain local businesses and municipal services. When lake levels drop or river flows decline, these communities experience cascading impacts, including reduced tax revenues and job losses in sectors such as lodging, food service, and transportation. The magnitude of these impacts would depend on the frequency and duration of low-elevation conditions, which would vary significantly across the alternatives.

Maintaining reservoir elevations and river flows within ranges that support recreation is critical for protecting the economic contributions and community well-being. For detailed analysis, including supporting data and tables, see the technical appendix sections for socioeconomics and recreation.

Issue 3: How would anticipated water shortages and changes in water levels in reservoirs and river segments affect access and the quality of nonmarket values?

Nonmarket values, such as scenic quality, opportunities for solitude, and cultural connections, are central to the Colorado River system and its surrounding landscapes. These values are not reflected in direct economic measures but are essential to visitor experiences and the cultural identity of tribes and gateway communities. Stable reservoir elevations and predictable river flows help maintain visual integrity, access to culturally significant sites, and the immersive qualities that define national parks and recreation areas (Flyr and Koontz 2024).

The alternatives that maintain relatively stable reservoir levels and minimize flow variability provide stronger protection for these intangible benefits. Under these scenarios, boating and rafting experiences retain their quality, the scenic character remains intact, and opportunities for solitude and reflection are disrupted less. These conditions also support traditional practices for tribes, which often depend on predictable water levels and access points for cultural and spiritual activities.

During wet hydrologic conditions, the range of alternatives would generally produce conditions where lake levels and flows along the Colorado River would result in minimal impacts on nonmarket values. As conditions become drier, however, the No Action Alternative and CCS Comparative Baseline would result in greater variability in reservoir elevations and river flows. This would result in the potential to expose barren drawdown zones, alter shoreline appearance, and reduce the aesthetic values tied to natural landscapes. Variability in flows can also affect the timing and accessibility of cultural practices, creating challenges for maintaining traditional uses. Visitors seeking a consistent wilderness experience may perceive degraded conditions when confronted with stark elevation changes or shortened seasons, which can influence perceptions of resource stewardship and long-term visitation patterns.

Under drier conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would be more robust in terms of the support for nonmarket values; this is due to maintenance of key reservoir thresholds that support access for boating and camping, as well as experiential benefits and cultural connections (see **TA 11**, Cultural Resources). The quality of river-based recreation is expected to remain high, due to increased stability with flow-dependent activities (see **TA 14**, Recreation). More frequent low-elevation conditions would be introduced in the Basic Coordination Alternative, which could noticeably affect the nonmarket values tied to lake-based recreation and scenic quality (see **TA 14**, Recreation) although at a reduced level compared with the No Action Alternative and the CCS Comparative Baseline.

Outcomes produced by the Supply Driven Alternative vary depending on the hydrology and location. In wet years, the nonmarket values supported would remain similar to those under the CCS

Comparative Baseline; however, in dry sequences, reduced reservoir elevations and altered flow regimes would diminish the scenic quality and access for boating and angling (see **TA 14**, Recreation) for Lake Powell. For Lake Mead, the Supply Driven Alternative is the most robust for supporting reservoir levels at Lake Mead, which would support the nonmarket values. River-based recreation would experience moderate variability in trip quality, while ecosystem services and the associated nonuse values would fluctuate with water availability (see **TA 8**, Biological Resources – Fish and Aquatic Resources).

Summary Comparison of Alternatives

The lowest impacts on economic and social conditions from reductions in agricultural production and increases in fallowed lands due to shortages in irrigation water, across all alternatives, states, and tribal and non-tribal irrigation entitlement holders, would occur under the No Action Alternative due to the low maximum shortage of 0.6 maf; however, across the action alternatives, impacts on economic and social conditions from changes in agriculture would vary across irrigation entitlement groups, based on the maximum shortage levels and water shortage distribution methods. For all irrigation entitlement holders except Arizona tribal, impacts on the economic and social conditions from agricultural activity would tend to be lower under the alternatives with a low maximum shortage level and priority shortage distribution methods, and impacts would tend to be higher under the alternatives with a high maximum shortage level or pro rata shortage distribution methods, compared with other action alternatives.

However, for Arizona tribal entitlement holders, lower impacts on economic and social conditions due to reductions in agricultural production would occur under alternatives with pro rata shortage distribution methods, and higher impacts occur under the alternatives with priority shortage distribution methods, compared with other action alternatives. Overall, the alternatives demonstrate a trade-off between shortage distributions across irrigation entitlement holders, flexibility in the maximum allowable shortage implementation, and the ability to support stable agricultural production and social well-being.

Operational changes under the proposed alternatives would influence these conditions in different ways. The alternatives that maintain more consistent reservoir levels would preserve boating access, marina operations, and shoreline recreational opportunities. This stability would support continued visitation and minimize disruptions to businesses dependent on tourism. Conversely, the alternatives that result in greater variability in lake elevations and river flows would affect the recreational quality and access and the related levels of contributions. Similarly, the alternatives that maintain consistent and adequate river flow below Glen Cayon Dam would offer continued support for recreational experiences with high value for whitewater boating and angling, and for the related spending in gateway communities and the regional economy.

The Supply Driven Alternative poses the greatest risk to recreation-based economies relying on economic contributions from reservoir-based recreation in Lake Powell, while the CCS Comparative Baseline and the No Action Alternative have the least robust modeled performance for supporting recreational opportunities and spending associated with Lake Mead recreation. In contrast, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in more consistent reservoir levels at Lake Powell to support recreation, and the Supply Driven Alternative would support the greatest level of contributions from recreation in Lake Mead. However, under all alternatives, access to launch facilities and safe navigation routes for Lake Powell and navigational challenges in Lake Mead would continue to impact lake-based recreational opportunities and the associated spending.

River-based recreation is also vulnerable to operational changes. Activities such as angling in Glen Canyon and whitewater rafting in Grand Canyon depend on stable flows to ensure safety and trip quality. Reduced flows shorten rafting seasons and diminish the overall experience, leading to lower demand for outfitter services and the associated hospitality sectors. While the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would offer more consistent flows than the other alternatives, it would not fully mitigate risks. The Enhanced Coordination Alternative would be the least robust at maintaining or exceeding the minimum desired daytime flows to support boating in Grand Canyon; it would also result in the greatest potential for a reduction in the recreational value for whitewater rafting and the associated regional economic contributions associated with these uses.

Nonmarket values, such as scenic quality, opportunities for solitude, and cultural connections, are central to the Colorado River system and its surrounding landscapes. In general, stable reservoir elevations and predictable river flows support these factors and the value for locals and visitors. As a result, the alternatives that maintain relatively stable reservoir levels and minimize flow variability would provide stronger protection for these intangible benefits. During wet hydrologic conditions, the range of alternatives would generally produce conditions where lake levels and flows along the Colorado River would result in minimal impacts on nonmarket values. As conditions become drier, however, the No Action Alternative and CCS Comparative Baseline would result in greater variability in reservoir elevations and river flows. This would result in the potential to expose barren drawdown zones, alter shoreline appearance, and reduce the aesthetic values tied to natural landscapes. Variability in flows can also affect the timing and accessibility of cultural practices, creating challenges for maintaining traditional uses. Visitors seeking a consistent wilderness experience may perceive degraded conditions when confronted with stark elevation changes or shortened seasons, which can influence perceptions of resource stewardship and long-term visitation patterns.

Under drier conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would generally be the more robust in terms of the support for key reservoir and river flow thresholds that support these resources and the associated values. In addition, the Supply Driven Alternative would result in the most robust preservation of Lake Mead's reservoir levels at thresholds to support resources with nonmarket values.

3.17 Population and Land Use

3.17.1 Affected Environment

This section explores the baseline conditions and potential impacts from proposed management on analysis area population dynamics and land use changes, with a focus on potential changes in developed lands and lands used for irrigated agriculture.

Sections TA 17.1.1, **17.1.4**, and **17.1.6** provide comprehensive baseline information to characterize the existing setting and trends related to population, general landownership and management, and developed land patterns. Information is also provided for municipal water, which supports developed land use. Data are provided related to historical agricultural land use to support the discussion of irrigated agriculture.

Due to the influence of municipal water availability on developed lands, the impacts analysis examines changes to water availability for municipal supply and the related impacts on population and land use changes. **Sections TA 17.1.2** and **17.1.3** provide detailed information on industrial and municipal water uses and study area municipalities.

Due to the influence of irrigation water availability on agricultural land use, the impacts analysis examines changes to irrigation water availability and related impacts on acres of lands in agriculture. **Section TA 17.1.5** provides detailed information on agricultural land use within the study area, including irrigated acres of harvested cropland and the percentage of irrigated water from surface water resources.

A high-level overview of key trends for population and land use is provided below.

Population

Population is a driver of demand for consumptive water use, particularly for municipal water. Communities throughout much of the western U.S. have followed trends of increasing populations over the past decade. In the analysis area, the population growth rate has generally been positive or stable. **Section TA 17.1.1** provides the historical and projected population for the Arizona, California, Nevada, and Utah analysis area counties.

The demographic landscape in these states reflects diverse trends over the past decade. Arizona has witnessed significant population increases, particularly in urban and suburban settings, driven by affordable housing and expanding job opportunities in emerging sectors. In Nevada, especially in the Las Vegas metropolitan area, rapid growth has been underpinned by tourism, hospitality, and related services. California continues to see varied population trends, with urban centers experiencing steady growth while certain rural regions face declines.

In Arizona, growth in some counties has reached over 30 percent, and Nevada's urban centers have seen substantial increases that exacerbate water demand and place stress on existing resource systems. California, with its large and diverse population, faces the challenge of balancing high urban density with water conservation measures, ensuring that residential and industrial growth complies with sustainable water use practices. Projections across the three states indicate continued growth that will necessitate further investments in water infrastructure and the revision of water allocation policies to meet increasing municipal demands. More detailed information is provided in **Section TA 17.1.1**.

Population growth can increase the demand for water for domestic, agricultural, and industrial use and increase pressure on existing water sources. Studies have shown that population growth can be a dominant driver of long-term municipal water demand (Liu et al. 2025). Insufficient water supply can constrain population growth and development by limiting an area's capacity to support residents.

Industrial and Municipal (Domestic) Water Uses and Trends

The Colorado River is a pivotal water source serving municipalities, industries, and agricultural operations in Arizona, Nevada, and California. **Section TA 17.1.2** provides a detailed overview of industrial and municipal (domestic)[18] water supply, demand, and use trends within the U.S. and the Lower Basin. **Section TA 17.1.3** provides information on the municipalities within Arizona, California, and Nevada with the potential to be affected by changes in domestic water availability. Municipal water systems in these regions face growing pressures from population growth, climate trends, and uncertainties in future water availability, demand, and technological or policy adoption (Liu et al. 2025). Water management strategies—including conservation measures, demand-side management, and technology upgrades—have been implemented to mitigate these pressures and maintain system reliability.

Although existing and ongoing municipal water management strategies do not change domestic water entitlement amounts, they illustrate how municipal systems have adapted—and may continue to adapt—to evolving water supply and demand conditions. This context is important for understanding how communities in the region would respond to variability in water availability under different future conditions.

The availability of domestic water is a key determinant of population growth and land use patterns in the region (**Section TA 17.1.2**). Peer-reviewed studies have documented the relationships between population growth, land use patterns, and domestic water delivery. Urban sprawl, characterized by low-density development and increased impervious surfaces, has been shown to elevate per capita water demand through higher outdoor water use (Heidari et al. 2021). In contrast, high-density development often reduces per capita water use and can lessen the frequency and severity of water shortages. Rapid urbanization and population growth can also increase pressure on existing water infrastructure, creating challenges in maintaining consistent domestic water delivery.

In some areas, such as Arizona, water availability is a prerequisite for development. For example, the state's Assured and Adequate Water Supply programs require developers to demonstrate a reliable 100-year water supply before proceeding with new projects. While not directly tied to Colorado River water, this is one example of how the regulatory framework can shape development patterns. Nevada and California have implemented similar regulatory frameworks, necessitating comprehensive water supply planning for new M&I projects. These collective measures demonstrate some ways in which the study area states are responding to the dual pressures of growing populations and water scarcity.

In models of projected water yield and demand in the western U.S. to 2070, data indicate that demands for municipal water are increasing across the socioeconomic analysis area, while projected water availability is decreasing (see, for example, Warziniack and Brown 2019). While this trend is seen throughout the western U.S., the Colorado River region has the largest percentage increases in

[18] Domestic water use includes the use of water for "household, stock, municipal, mining, milling, industrial, and other like purposes" (1922 Colorado River Compact, section II(h)).

projected domestic water use and the greatest percentage decreases in projected water yield from all sources, including Colorado River water (Warziniack and Brown 2019).

Land Use

This section describes existing land use conditions along the mainstream Colorado River from Glen Canyon Dam to the U.S.–Mexico border. Land use includes recreation, agriculture, tribal land use, conservation and habitat management, residential and urban development, and utility and infrastructure corridors.

Landownership along the Colorado River is highly variable and includes federal (NPS, BLM, FWS, and Reclamation), tribal, state, and private lands. Federal agencies manage much of the land in the upper and middle portions of the river corridor, particularly in areas surrounding Glen Canyon NRA, GCNP, Lake Mead NRA, and multiple NWRs. Tribal lands are prominent in both Arizona and California. State and private lands are more common in the Lower Basin, especially in urban areas like Bullhead City and Yuma and along agricultural corridors in California and Arizona.

Developed land uses occur in concentrated areas where communities and infrastructure directly rely on the Colorado River. These include recreation sites, marinas, campgrounds, roadways, water delivery systems, hydropower infrastructure, and municipal areas. While most of the corridor remains undeveloped, developed areas have expanded since the early 2000s in several locations due to population growth, recreational demand, and infrastructure upgrades. Agricultural lands are also a major land use along the river's lower reaches, particularly in western Arizona and southeastern California, where irrigated farming depends heavily on surface water deliveries.

Reservoir elevations and river flow conditions strongly influence how land near the river is used and managed. Declining water levels at Lakes Powell and Lake Mead have resulted in increased shoreline exposure, changes in recreational access points, and new management needs for erosion control, sediment exposure, and public safety. These hydrologic shifts also affect agricultural land use by altering water availability for irrigation, which can contribute to fallowing or shifts to less water-intensive crops in some areas.

Agricultural Land Use

Agriculture is a major land use along the lower Colorado River, particularly in western Arizona and southeastern California, where irrigated farming relies heavily on surface water deliveries. Key agricultural areas include Yuma, La Paz, and Mohave Counties in Arizona and Imperial and Riverside Counties in California. These regions support extensive production of food, feed, and fiber crops and represent some of the most productive irrigated farmland in the country. Western Arizona counties such as Pinal, Maricopa, and Pima also contain irrigated agricultural lands, although these areas have experienced reductions in irrigated acreage over time due to water availability constraints. Trends in county-level cropland data show shifts in harvested and irrigated acreage across the region, reflecting long-term drought, changes in water deliveries, and adaptation by agricultural producers (Dieter et al. 2018; Presson and Eden 2023; USDA NASS 2024). More detailed information on the location and extent of irrigated agricultural lands is provided in the technical appendix.

3.17.2 Environmental Consequences

Methodology

The analysis of population and land use impacts evaluates how operational changes and changes to domestic water delivery could affect overall population and land use patterns, including developed lands for residential and commercial uses and lands used for irrigated agriculture.

To analyze how operational changes may affect population and land use patterns, the DMDU analysis was used. The DMDU analysis of domestic water impacts used modeled shortages to domestic users provided by the SAMs and ADMs[19] and proceeded in two main steps. First, domestic priorities were grouped (for example, Arizona CAP NIA-A/B, CAP M&I, Arizona Priorities 2–3, PPRs, California Priority 4 and PPR, and Nevada priorities). Second, the domestic modeled shortage was analyzed for each priority group to determine the shortage levels at which the group's average percentage shortage equaled approximately 20, 40, 60, 70, 80, or 100 percent of its total entitlement. These thresholds were applied within the DMDU framework to develop **Figures TA-17-2** through **TA-17-9**, which depict the percentage of modeled futures where each priority group maintains the specified fraction of normal water deliveries in 90 percent of years across the action alternatives. For the purpose of this analysis, "normal delivery" is defined as a full Colorado River or CAP entitlement supply. The figures provide a direct comparison of domestic water impacts across priority groups and the alternatives.

To analyze how operational changes may affect agricultural land use, this analysis relied on modeled shortages to irrigation users at the state level, produced by the SAMs. For more detailed information on the SAMs and consumptive impacts on irrigation users, see **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation. For more information on water deliveries and shortage impacts, including those for irrigation, refer to **TA 4**, Water Deliveries.

Impact Analysis Area

The analysis area for the population and land use section is separated by state and is the same for both population and land use issues. The impact analysis area is defined by those counties that may be affected by management direction that could result in water shortages to domestic and irrigation users. As described above, both issue statements rely on the SAMs. As a result, the analysis area is informed by the SAMs and includes the counties represented in the SAMs. The Arizona analysis area consists of Apache, Coconino, Gila, La Paz, Maricopa, Mohave, Navajo, Pima, Pinal, and Yuma Counties. These include counties that are directly adjacent to Lake Powell, Lake Mead, or the Colorado River and counties in which shortages would likely occur. The California analysis area consists of Imperial, Los Angeles, Orange, Riverside, San Bernardino, and San Diego Counties. The Nevada analysis area consists of Clark County. The Nevada analysis area was limited to Clark County because Clark County is adjacent to Lake Mead and encompasses SNWA's service area and other individual water providers. Shortages in Nevada would be limited to SNWA's service area.

[19] There are three unique SAMs and five ADMs to capture the nuances of the alternatives and sensitivity analyses; these are further explained in **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation.

Assumptions

- Colorado River operations do not directly control population change, but they may indirectly influence migration patterns.
- Local socioeconomic conditions and demographic trends may also be influenced by factors outside river operations, such as housing costs, infrastructure investment, local attitudes towards water conservation, and regional employment patterns.

Impact Indicators

- Shortage to domestic water users
- Acres of developed land within the analysis area and the potential for changes based on municipal water availability
- Acres of irrigated agricultural land within the analysis area and the potential for changes based on agricultural water availability

Issue 1: How would operational changes affect population and developed land use patterns?

This issue examines how different operational strategies may influence population dynamics and developed land use patterns in communities that rely on Colorado River water for municipal water uses. While Colorado River operations do not directly determine population movement or developed land use patterns, long-term changes in water availability and recreational access may influence migration patterns and developed land patterns. This issue statement is analyzed by first presenting the DMDU figures and a detailed analysis for domestic water delivery and then by assessing how domestic water delivery impacts would impact population and developed land use patterns.

Figure TA 17-2 through **Figure TA 17-9** in **TA 17**, Population and Land Use, display potential impacts on domestic water deliveries by presenting the percentage of normal domestic water deliveries that can be achieved across a range of modeled futures. Each figure illustrates the percentage of normal domestic water deliveries achieved in 90 percent of years over a 34-year modeling period, representing varying percentages of potential future scenarios for each priority group. The rows indicate different levels of normal delivery; higher rows denote higher volumes that are more challenging to achieve, while lower rows indicate more frequent modeled shortages. The analysis designates greater than 80 percent of normal delivery in 90 percent of years as the preferred minimum performance level, highlighting this row as it most closely approximates normal domestic water delivery and represents the least induced shortage.

In addition, each figure includes a bottom row that shows futures with dead pool–related reductions. These occur when Lake Mead lacks sufficient water to meet downstream demands or when Hoover Dam infrastructure limitations force releases below the required volume, typically when the lake approaches dead pool (895 feet) or even earlier (up to 950 feet). Although this analysis does not address the allocation of reductions related to dead pool, displaying these figures provides important context on the robustness of the alternatives.

The alternatives with greater robustness would likely result in fewer potential indirect impacts on population growth and developed land. Greater robustness corresponds to a higher percentage of futures in which domestic water delivery remains consistent with normal conditions and shortages occur less frequently. In contrast, less robust alternatives are more susceptible to reductions in domestic water availability due to more shortages. These shortages could manifest as reduced water deliveries, delivery restrictions, or the need for additional conservation measures, which could in turn limit the capacity to meet domestic water demand. A more robust alternative would therefore help ensure that domestic water supplies remain reliable to support existing populations and accommodate anticipated future growth, thereby minimizing potential secondary impacts on development patterns and land use.

The SAMs used to inform the DMDU analysis do not incorporate water management measures, such as conservation programs, or demand-reduction strategies. These measures do not change entitlement amounts or shortages; however, as noted in the affected environment section, conservation programs and other management strategies can influence domestic water demand and help mitigate the operational pressures associated with shortages, uncertain supply, and population growth. The potential impacts on domestic water supply for the Lower Division States would also depend in part on existing and future management strategies and conservation measures implemented by the states, local water providers, and individual users. Potential impacts would also depend on other external factors such as environmental and economic conditions.

Table 2-10, Summary of Potential Effects, Population and Lands, in **Chapter 2** provides an overview of impacts on population, lands, and domestic water by alternative based on the DMDU figures discussed in detail in **TA 17**, Population and Land Use. The table demonstrates how the different alternatives perform in terms of the percentage of normal delivery in potential futures. The table with a summary of effects on the population and lands includes two performance indicators: greater than 80 percent of normal delivery and greater than 60 percent of normal delivery in 90 percent of modeled futures, across the full modeling period. The table displays how each alternative performs for these two performance indicators, by priority group. The performance indicators illustrate how each alternative performs in maintaining domestic water deliveries under a wide range of uncertain future conditions. The alternatives that would achieve greater than 80 percent of normal delivery in 90 percent of years demonstrate strong robustness, indicating that domestic deliveries would remain near normal levels across most modeled futures. These alternatives would result in fewer and less severe shortages, which would provide greater reliability for domestic water users. This performance indicator is difficult to achieve under many alternatives.

To show further variation across the alternatives, **Table 2-10**, Summary of Potential Effects, Population and Lands, in **Chapter 2** includes greater than 60 percent of normal delivery in 90 percent of years. The alternatives that only meet the greater-than-60-percent-of-normal-delivery-in-90-percent-of-years threshold demonstrate lower robustness. Under these conditions, more frequent domestic delivery reductions or shortages could occur in modeled futures, particularly for junior priority groups. Such outcomes could increase the likelihood of secondary socioeconomic impacts, including constraints on growth or secondary changes in land development patterns.

As described in **Section TA 17.1**, Affected Environment, and **Section 3.1**, Introduction, above, peer-reviewed studies document that domestic water availability significantly influences population dynamics and land use. **Section TA 17.2.3**, DMDU Analysis Summary, provides a detailed overview of potential impacts on domestic water and the associated impacts on population and land use patterns for Arizona, Nevada, and California. Key summaries are also provided below.

Arizona: For Arizona PPR and Arizona Priorities 2 and 3, all alternatives achieve the preferred minimum performance of over 80 percent of normal delivery in 90 percent of years, across the full modeling period, excluding the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives. For Arizona Priorities 2 and 3, over 80 percent of normal delivery in 90 percent of years, across the full modeling period, occurs in 57 percent of potential futures under the Maximum Operational Flexibility Alternative. For Arizona CAP Indian, CAP M&I, and 4i priorities, no alternative achieves the preferred minimum performance level of over 80 percent of normal delivery in 90 percent of years. However, the Enhanced Coordination Alternative allows for over 60 percent of normal delivery in 100 percent of modeled futures for these priority groups, demonstrating its robustness compared with the other alternatives.

When considering all Arizona priority groups, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives generally demonstrate the most robust performance for domestic water entitlements, based on maintaining greater than 60 percent of normal delivery in at least 90 percent of years across the full modeling period, for the greatest number of users. Compared with the CCS Comparative Baseline and No Action Alternative, under these alternatives 60 percent or more of normal domestic water delivery occurs across the largest percentage of potential futures and for the greatest number of priority groups. While this approach maximizes delivery reliability for more users overall, it involves a trade-off: Some senior entitlements would experience delivery reductions that would not occur under priority distribution, whereas more junior entitlements may continue to receive near-normal deliveries, across the modeled futures. This allocation reflects a balance between broad delivery coverage and the reallocation of shortage risk across the priority groups.

California: For California PPR 3, all alternatives, excluding the Enhanced Coordination Alternative, achieve the preferred minimum performance level of over 80 percent of normal delivery in 90 percent of years, across the full modeling period. For California Priority 4, the No Action, Basic Coordination, and Supply Driven (LB Pro Rata approach) Alternatives achieve the preferred minimum performance of over 80 percent of normal delivery in 90 percent of years, across the full modeling period.

When evaluating both California priority groups together, the Supply Driven Alternative (LB Pro Rata approach) is the most robust, compared with the No Action Alternative and all other action alternatives. It provides 100 percent of normal delivery to California PPR and California Priority 4 in 90 percent of years across 100 percent of potential futures. Additionally, considering the dead pool–related reductions, which could affect these users, the Supply Driven (LB Pro Rata approach) Alternative has the lowest percentage of futures with constrained releases (7 percent), compared with all other alternatives. Reliable domestic water deliveries under the Supply Driven (LB Pro Rata approach) Alternative would support continued population growth and land development in areas served by California PPR and Priority 4.

Maintaining near-normal deliveries reduces the likelihood of constraints on new development, housing availability, and municipal services that rely on water supply. In contrast, the alternatives with lower reliability or greater exposure to dead pool–related reductions could limit opportunities for residential and commercial growth, particularly in high-demand areas, and could influence land use patterns or delay new construction. Ensuring robust water delivery across multiple futures is therefore directly tied to supporting sustainable population growth and land use planning in California.

Nevada: Similar to Arizona and California PPR, for Nevada Priorities 1–7, all alternatives, excluding the Enhanced Coordination Alternative, achieve the preferred minimum performance level of over 80 percent of normal delivery in 90 percent of years, across the full modeling period. In contrast, for Nevada Priority 8, the No Action Alternative is the only alternative that meets the preferred minimum performance.

When considering both Nevada priority groups together, the Basic Coordination Alternative, followed by the Supply Driven (LB Pro Rata approach) Alternative, provides the most robust performance. These alternatives deliver greater than 80 percent of normal domestic water across the largest percentage of potential futures and for the greatest number of priority groups. Robust domestic water deliveries are critical to supporting population growth and land development in Nevada. The alternatives that maintain reliable deliveries for both priority groups reduce the risk of constraints on new housing, commercial development, and essential municipal services that depend on water supply. Conversely, the alternatives with lower reliability, particularly for Nevada Priority 8, could limit the capacity of communities to expand, influence land use patterns, or delay new construction projects. By sustaining domestic water availability across a broad range of potential futures, the Basic Coordination and Supply Driven (LB Pro Rata approach) Alternatives help support stable population growth and more predictable land use planning across the state.

Issue 2: How would operational changes affect irrigated agricultural land use patterns?

Irrigated agriculture in Arizona and California remains sensitive to changes in Colorado River operations. Across all modeled alternatives, reductions in irrigation deliveries occur as reservoir elevations decline and system shortage volumes increase. Differences among the alternatives primarily reflect how shortages are distributed, either according to priority systems or through coordinated or pro rata sharing, and whether conservation and flexibility mechanisms are available to offset impacts.

Arizona experiences the greatest exposure to shortages under most alternatives because many western Arizona counties' irrigation users hold junior priority rights. Under conditions without new conservation or shortage-sharing mechanisms, such as the No Action and Basic Coordination Alternatives, Arizona irrigation users face frequent and severe reductions. Literature indicates that these reductions can accelerate fallowing, crop switching, and farmland retirement in western Arizona counties (USGS 2019b; Arizona Extension 2024; Presson and Eden 2023). Even under the

CCS Comparative Baseline, modeled shortages still affect Arizona at low to mid-levels of system stress, reflecting ongoing vulnerability despite existing conservation programs.

California agriculture, particularly in senior-rights districts, such as the Imperial Valley, is less affected under priority-based alternatives; however, it faces greater reductions under coordinated or pro rata frameworks. The Enhanced Coordination and Supply Driven (Pro Rata approach) Alternatives distribute shortages more evenly across Lower Basin water users, reducing concentrated impacts in Arizona but increasing exposure for California. Studies show that even modest reductions can influence land use in California's irrigation districts through shifts toward drought-tolerant crops or partial land retirement (Prakash 2023; Lee et al. 2020).

The alternatives that incorporate operational flexibility or large conservation reserves, such as the Maximum Operational Flexibility Alternative and portions of the Supply Driven Alternative, may lessen the severity of shortages during milder hydrologic periods, though long-term reliability still depends heavily on conservation participation and system conditions. Research indicates that agriculture increasingly relies on adaptive practices, such as deficit irrigation and crop switching, to maintain productivity under prolonged water scarcity (USDA ERS 2021).

The analysis shows that operational changes to the Colorado River system would continue to influence land use in irrigation-dependent regions. Concentrated shortages under priority-based operations are most likely to drive localized land fallowing and economic disruption in central Arizona, while pro rata or coordinated approaches lead to broader, more evenly distributed impacts in Arizona and California. More detailed modeling results and county-level outcomes are provided in the technical appendix.

Summary Comparison of Alternatives

Population and Developed Land Use: The alternatives vary in how they distribute domestic shortages and in their potential to impact domestic water deliveries and in turn indirectly impact population dynamics and land use within the analysis area.

As shown in **Table TA 17-17**, for the No Action, Basic Coordination, Maximum Operational Flexibility, and Supply Driven (LB Priority approach) Alternatives, which apply a priority-based distribution of shortage, under most modeled futures, water users with senior entitlements would likely continue to experience relatively consistent domestic water deliveries. This is because these entitlements are contractually prioritized during periods of reduced supply. However, junior entitlements could face greater reductions in water deliveries during Shortage Conditions. Consequently, while senior entitlement holders may maintain service levels closer to normal, junior entitlement holders could experience more frequent or severe delivery constraints.

Under the No Action, Basic Coordination, Maximum Operational Flexibility, and Supply Driven (LB Priority approach) Alternatives, greater than 80 percent of normal domestic delivery to most senior entitlements occurs in all potential futures. The specific Arizona, California, and Nevada senior entitlements vary by alternative (see **Table TA 17-17**). Because these alternatives have greater robustness for senior priority groups, there could be fewer potential indirect impacts on population growth and land development. A higher percentage of potential futures with greater than 80 percent of normal delivery could support future population growth, water demand, and development in areas serviced by these priority groups.

Under the No Action, Basic Coordination, Maximum Operational Flexibility, and Supply Driven (LB Priority approach) Alternatives, for junior entitlements there are fewer potential futures in which there is any percentage of normal delivery. Domestic shortages could manifest as reduced water allocations, delivery restrictions, or the need for additional conservation measures, which could in turn limit the capacity to meet domestic water demand. Should shortages result in a reduction or elimination of legal access to municipal water, widespread impacts on social and economic conditions could also be possible. In some scenarios, municipalities could find the need to pursue alternative water sources or hauled water, if available, as an alternative to support continued services.

In addition, indirect social costs could occur as a result of a reduction in ecosystem services; also, indirect social costs could occur from a reduction of benefits to people provided by the environment. For example, trees in urban areas have been shown to provide high levels of benefits to people in the form of shade (mitigating urban heat impacts), local air quality improvements, and enhancement of the visual setting. Should a reduction in domestic water supply result in die-offs of urban and suburban area trees, this could represent a loss of value that would take decades to recapture, due to the growth time required for trees (see, for example, Bloome et al. 2016).

As shown in **Table TA 17-17**, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives, which apply pro rata distribution of shortage under most modeled futures, would generally allow a larger number of priority groups to receive domestic water deliveries closer to normal conditions. While a pro rata approach would change the distribution of water across all users during shortages, this section solely focuses on the distribution of water to domestic users. This approach would deviate from the priority-based distribution, resulting in some modeled reductions to domestic deliveries for senior entitlement holders who would otherwise maintain normal domestic delivery under the existing priority system. In contrast, more domestic junior priority water entitlement holders would continue to receive some level of water supply under this approach. Essentially, the pro rata method would result in more existing users receiving moderate water deliveries during shortages through a redistribution of water from senior entitlements.

Agricultural Land Use: The alternatives vary in how they distribute irrigation shortages and in their potential to influence long-term land use patterns. The No Action and Basic Coordination Alternatives rely on priority-based distribution and result in concentrated impacts on junior priority users in Arizona, particularly in western Arizona counties, with limited mitigation tools. These conditions increase the likelihood of fallowing, crop switching, and economic stress in affected communities. The CCS Comparative Baseline offers more predictability and flexibility, helping buffer some impacts, though shortages still occur.

The Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives distribute shortages more broadly across the states and users, reducing concentrated impacts on junior priority holders but introducing greater reductions in California, which could lead to more widespread land use changes. The Maximum Operational Flexibility and Supply Driven (LB Priority approach)

Alternatives incorporate adaptive tools and conservation reserves, offering potential buffers against extreme shortages; however, their effectiveness depends on stakeholder participation and hydrologic conditions.

3.18 Indian Trust Assets

3.18.1 Affected Environment

The United States has a trust responsibility to tribes, as defined by statutes, court decrees, treaties, or other applicable law.[20] Indian trust assets (ITAs) are legal interests in assets held in trust by the federal government for the benefit of federally recognized Native American tribes or individual Native Americans (Reclamation 1994). ITAs can be located on or off established reservation lands and can consist of land; rights or entitlements;[21] natural resources; monies (for example, trust funds); mineral rights; hunting, fishing, trapping, and gathering rights; and others. Beneficiaries of the Indian trust relationship are tribes and individual Native Americans; the United States is the trustee. ITAs are generally restricted against alienation. With federal authority and approval, ITAs may be leased to generate income for tribes or individual Native Americans (Department 2025).

It is the Department's general policy to carry out activities in a manner that protects ITAs and avoids adverse effects whenever possible (Reclamation 1993). In accordance with Reclamation Indian Trust Asset Policy and Guidance (Reclamation 1994), tribal consultation addressing trust assets should be initiated with appropriate tribal groups and the BIA, and the presence or absence of ITAs should be addressed explicitly in all NEPA documents. Reclamation is consulting with tribes regarding the proposed Post-2026 Operational Guidelines.

The following sections summarize the affected environment for different types of ITAs. See **TA 18**, Indian Trust Assets, for additional detail.

Trust Lands

Indian trust lands are lands that the United States holds in trust for the benefit of a tribe (tribal trust land) or for an individual Native American (individual trust land). Trust lands may be located on or off a reservation. While reservations are not always synonymous with trust lands, the exterior boundaries of reservations are used to define the trust land assets for purposes of this NEPA analysis. There are 30 federally recognized tribes in the Colorado River Basin; of these, 29 of which have established reservations (**Figure TA 18-1**). Tribal land uses include, but are not limited to, communal and spiritual uses, domestic use, and agricultural and economic development.

Water Entitlements, Water Deliveries, and Storage and Conservation Options

TA 4, Water Deliveries, summarizes the Law of the River that governs management and operation of the Colorado River. **TA 18**, Indian Trust Assets, includes a discussion of tribal mainstream

[20] Nothing in this section or **TA 18**, Indian Trust Assets, is intended to modify, abrogate, or create ITAs. Any particular ITA remains defined by and subject to applicable authority.

[21] Rights and entitlements may be used interchangeably in this section and in **TA 18**, Indian Trust Assets, for simplicity, and no legal change to any ITA is intended.

Colorado River water entitlements and CAP contracts.[22] The entitlements included in this analysis are consistent with those in the SAMs and ADMs (see **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation) and other sections of the EIS.[23]

Other Indian Trust Assets

ITAs can also include hunting, fishing, trapping, and gathering rights; mineral rights; and cultural, biological, and other resources. Whether specific rights or resources legally qualify as an ITA is complicated and depends on multiple factors, such as land status (Reclamation 1994). Reclamation is consulting with tribes and the BIA to identify ITAs. To date, potential changes in water deliveries and activities affected by potential changes in water deliveries (for example, irrigated agriculture) have been the primary concerns related to ITAs. Other ITAs may be incorporated into this analysis for the Final EIS, depending on tribal input.

Reclamation acknowledges that the 30 Basin Tribes depend on the Colorado River and its tributaries for a variety of purposes, including cultural and spiritual activities, wildlife, instream flows, recreation, and other purposes. See **TA 13**, Tribal Resources, and **TA 11**, Cultural Resources, for analysis of tribal and cultural resources, respectively. In general, those analyses apply to tribal and cultural resources that qualify as ITAs.

Although income derived from ITAs is not an ITA in and of itself, income derived from ITAs, such as agricultural products, water leases, and fees charged for outdoor recreation on tribal land, can be an important source of income for tribes. While this is more of a socioeconomic issue, income derived from ITAs may be considered further in an appendix of the Final EIS, depending on tribal input.

3.18.2 Environmental Consequences

According to Reclamation's ITA policy, actions that affect the value, use, or enjoyment of ITAs should be discussed in an ITA assessment (Reclamation 1994).

Methodology

The methodology varies for each type of ITA. Quantitative metrics are analyzed where possible; otherwise, a qualitative discussion is provided. Refer to **Section TA 18.2.1**, Methodology, for more information on the methodology used. As described in Section 3.4.1, the geographic scope of this EIS does not extend above Lake Powell and accordingly does not include an analysis of the impact to Upper Basin water users.

Impact Analysis Area

The impact analysis area includes land within the boundaries of reservations and off-reservation trust land within the Colorado River Basin (29 reservations are listed in **Section TA 18.1**).[24]

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[22] While some entitlements are not ITAs, they are included for reference in **TA 18**, Indian Trust Assets.

[23] Tribes may have other sources of water, including groundwater and other surface water, which are not part of this analysis.

[24] As discussed **in Section 3.18.1**, one of the 30 Basin tribes does not have an established reservation; therefore, there are 29 reservations.

Assumptions

- Trust land includes land within the borders of established reservations and off-reservation trust land.
- For the water deliveries analysis, the assumptions of the CRSS modeling (**Appendix A**, CRSS Model Documentation) and SAM modeling (**Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation) apply.
- For potential impacts on agricultural land, the assumptions of the agricultural modeling apply (see **TA 16**, Socioeconomics, for more details).

Impact Indicators

- Changes in acres of irrigated tribal agricultural land in the Lower Basin
- Percentage of normal water delivered to Upper and Lower Basin tribes

Issue 1: How would changes in dam operations affect tribal water rights, water deliveries, and water storage and conservation options?

Some alternatives (for example, the No Action, Basic Coordination, and Supply Driven [LB Priority approach] Alternatives) maintain existing Lower Basin priority systems, while the other alternatives deviate from them. In addition, some alternatives would affect the available options pertaining to water storage and conservation of water for both Upper and Lower Basin tribes.

With respect to potential tribal water deliveries, the alternatives can be distinguished based on the following characteristics:

- The maximum shortage, which affects the relative frequency and severity of Lower Basin water shortages, including potential dead pool–related reductions.
- The method used to allocate Lower Basin water under shortages (for example, priority or pro rata distribution). Priority refers to the order in which entitlements are to be satisfied based on existing statutory, case law, and contractual provisions. The pro rata approach, in contrast, refers to dividing shortages differently across water users.
- Options for tribes and other water users to conserve and store water in Lake Powell or Lake Mead.

Figure TA 18-2 and **Table TA 18-5** in **TA 18**, Indian Trust Assets, summarize the alternatives based on these characteristics. The following sections summarize the anticipated effects of the alternatives on water deliveries and the storage and conservation options.

Upper Basin

Water Deliveries

No alternative would directly or indirectly affect Upper Basin tribal water entitlements. As discussed below, water storage and conservation mechanisms under some alternatives could indirectly affect the amount of stored conservation water available to Upper Basin tribes.

Storage and Conservation Options

The No Action and Basic Coordination Alternatives have no new water storage mechanisms and would not affect water storage and conservation by Upper Basin tribes. The other three alternatives do have new storage and conservation mechanisms. See **Chapter 2**, Description of Alternatives, for a full description of these mechanisms and how they would operate. Note that in all cases, stored water would be available for water transactions with other Upper Basin water users, both within and across Upper Division States.

Lower Basin

Water Deliveries

In this analysis, three main factors combine to determine the potential Lower Basin tribal water deliveries in any given year:[25] (1) the severity of potential shortages, (2) the distribution method used to allocate water under shortages, and (3) the frequency of dead pool–related reductions. [26] This analysis focuses on the first two factors. The third factor, dead pool–related reductions, is not a focus of this analysis.[27] In general, Reclamation anticipates acting to minimize dead pool–related reductions. However, the methods for doing so and the methods for allocating water under a dead pool–related reduction are unknown and too speculative to be included in this EIS.

Figure TA 18-3 in **TA 18**, Indian Trust Assets, illustrates how the percentage of normal water delivery changes as shortages become more severe under different distribution methods. For the purposes of this analysis, tribes are aggregated into the following four groups based on entitlement priorities:

- The "AZ CAP NIA" group has the most junior entitlements and includes tribes with Arizona CAP NIA-A and NIA-B priorities. This group consists of four tribes with contracts totaling approximately 177,000 afy.
- The "AZ CAP Indian, CAP M&I, and AZ 4i" group includes tribes with Arizona CAP Indian, CAP M&I, and Arizona 4i priorities. This group consists of 13 tribes and 16 individual entitlements (including mainstream water reserved for future settlement and unallocated), totaling approximately 374,000 afy.
- The "AZ 3" includes one tribe with Arizona third priority, totaling 50,000 afy.
- The PPR group is the most senior entitlements; this group includes five tribes in all three Lower Division States. This group of five tribes includes 15 discretely quantified entitlements totaling approximately 503,000 afy.

The DMDU analysis integrates information on the percentage of futures in which different amounts of shortages are estimated to occur under the different alternatives. For tribal water deliveries, deliveries of 20, 40, 60, and 80 percent of normal deliveries are modeled. The results show the

[25] The phrase "potential water deliveries" is intended to recognize that some tribal water entitlements are not fully developed or utilized. For simplicity, this analysis assumes that water deliveries and water entitlements refer to the same quantities of water.
[26] Conditions that might cause a dead pool–related reductions are described in **TA 4**, Water Deliveries.
[27] Modeling results related to the potential frequency of dead pool–related reductions are discussed further below.

percentage of futures in which these thresholds are met in 90 percent or more of the years within each modeled future.

The DMDU figures are presented in **Figure TA 18-4** through **Figure TA 18-12** in **TA 18**, Indian Trust Assets. Solely for the purposes of considering vulnerability within the DMDU modeling framework, a "preferred minimum performance" outcome is defined as a future trace in which at least 80 percent of normal water deliveries are estimated to be delivered in at least 90 percent of the years in a modeled future. In contrast, an "undesirable performance" future means that the preferred minimum performance criteria are not met. The 80 percent threshold was chosen as the preferred minimum performance because it is the model outcome with the largest quantity of water delivered.[28]

Key findings differentiating the alternatives based on the DMDU modeling are listed below. See **Section TA 18.2.2** for additional details, including key findings by priority group.

- There is no alternative that is the most robust across the priority groups in terms of maximizing water deliveries to all tribes. The alternatives perform differently for the priority groups. For some priority groups, the performance depends on the importance placed on results, considering only shortages relative to the frequency of futures with dead pool–related reductions.
- Considering shortages only (that is, not considering dead pool–related reductions), the No Action Alternative is estimated to meet the preferred minimum performance criteria in 100 percent of normal water deliveries to all priority groups except the AZ CAP NIA group. This result is likely due to a lower maximum shortage compared with the other alternatives. However, the No Action Alternative has the highest potential for dead pool–related reductions of any alternative, with 70 percent of futures estimated to have dead pool–related reductions. Therefore, water delivery would be unlikely under the No Action Alternative.
- The CCS Comparative Baseline is similar to the No Action Alternative, except 22 percent of futures meet the preferred minimum performance criteria for the CAP Indian, CAP M&I, and AZ 4i priority group, and 6 percent of futures meet the preferred minimum performance criteria for the CAP NIA group. Dead pool–related reductions are estimated to occur in 50 percent of modeled futures, which is less frequent compared with the No Action Alternative.
- The Basic Coordination Alternative is not among the robust alternatives for any priority group.
- The Enhanced Coordination Alternative has a more complicated pattern of robustness. Twenty-one percent of futures meet the preferred minimum performance criteria for all priority groups; this is less than some other alternatives. This is likely because shortages start relatively early compared with the other alternatives, and there is a high maximum shortage (see **Figure TA 18-2** and **Table TA 18-5** in **TA 18**, Indian Trust Assets). However, this alternative performs well in terms of delivering at least 60 percent of normal water, as it does so in 91–100 percent of modeled futures for all priority groups. This result is likely due, in

[28] In this context, "preferred minimum performance" and "undesirable performance" are terms selected to understand a modeling analysis, and they do not imply any policy, legal conclusion, or other conclusions about the analysis or ITAs.

part, to its use of the pro rata distribution method. Finally, this alternative has 16 percent of futures with dead pool–related reductions, which is among the fewest of the options modeled.

- Considering only shortages, the Maximum Operational Flexibility Alternative is more robust than the Enhanced Coordination Alternative for the two more senior water entitlements groups (PPR and AZ 3) and is less robust than the Enhanced Coordination Alternative for the two less senior water entitlements groups (AZ CAP Indian, M&I, and 4i; CAP NIA). It has the lowest percentage of futures with dead pool–related reductions (9 percent) of all the options modeled.
- The Supply Driven Alternative (LB Priority approach) generally is similar or less robust than the Maximum Operational Flexibility Alternative with respect to shortages for three of the four priority groups and has a higher percentage of futures with dead pool–related reductions (24 percent).
- The Supply Driven Alternative (LB Pro Rata approach) is closest to the Enhanced Coordination Alternative but does not meet the preferred minimum performance criteria as often; therefore, it is less robust.

Storage and Conservation Options

The No Action and Basic Coordination Alternatives have no water storage mechanisms that would affect Lower Basin tribes or the quantities of water available to them. Under both alternatives, water conserved under previous mechanisms that remains in Lake Mead in 2027 would be delivered in accordance with existing agreements. The other three alternatives do contain new water storage and conservation mechanisms. See **Chapter 2**, Description of Alternatives, for a full description of these mechanisms and how they would operate. Note that in all cases, stored water would be available for water transactions with other Lower Basin water users, both within and across the Lower Division States. The Enhanced Coordination Alternative is unique in that it explicitly allows for compensating tribes for water used to contribute to a federally managed conservation pool in Lake Mead. See **Section TA 18.2.2** for additional details.

Issue 2: How would changes in dam operations affect Indian trust lands?

Changes in dam operations under the different alternatives would not affect the borders of established reservations or the definitions of any trust lands. However, the different alternatives would affect the value, use, or enjoyment of trust lands. An important aspect of the value and use of trust lands involves agricultural land, as fluctuations in water levels are estimated to result in some tribal agricultural lands being fallowed. Other changes in the use or enjoyment of tribal land and resources are discussed in **TA 13**, Tribal Resources. The considerations therein generally apply to trust and non-trust resources.

Agricultural Land

The potential impacts of changes in dam operations on agricultural land are assumed to be inversely dependent on water deliveries, meaning agricultural impacts are estimated to increase as water deliveries decrease.

Upper Basin

As noted in the Upper Basin water deliveries section above, no alternative would directly affect water deliveries to the Upper Basin tribes. However, changes in storage and conservation options under some alternatives could indirectly affect the tribes' ability to manage their water. All else equal, the alternatives that provide new mechanisms for conserving and storing water for Upper Basin tribes (the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives) would benefit tribal agricultural operations in the Upper Basin.

Lower Basin

TA 16, Socioeconomics, discusses the potential impacts of changes in dam operations and the resulting changes in water deliveries on tribal and non-tribal agricultural economies in the Lower Basin. Estimates are presented for several socioeconomic metrics: acres of fallowed agricultural land, direct market value, jobs, and economic output. Results are presented at the state level for Arizona, California, and Nevada. See **TA 16**, Socioeconomics, for a full discussion of the modeling and results. This section focuses on the acres of fallowed land as an indicator of potential impacts on trust land.

Table TA 18-6 summarizes the modeling results for estimated changes in fallowed tribal agricultural land. Some key findings include the following:

- As indicated in the Lower Basin water deliveries analysis above, the seniority of water entitlements combined with the distribution method makes a large difference in the results.
- Tribal agriculture in Arizona is estimated to experience the largest impacts in terms of the absolute changes in acres of fallowed land. This is likely because the majority of the reservation land is in Arizona (see **Figure TA 18-1** in **TA 18**, Indian Trust Assets).
- No alternative is clearly the most robust for Arizona. The different alternatives and the CCS Comparative Baseline have varying trade-offs between fallowed acreage under shortages and the percentage of futures with dead pool–related reductions.
- In California and Nevada, impacts are only associated with the alternatives that use the pro rata distribution (the Enhanced Coordination and Supply Driven [LB Pro Rata approach] Alternatives). All the other alternatives and the CCS Comparative Baseline use some variation of the priority system and estimate no reductions in water deliveries; therefore, there would be no fallowed agricultural land in these states.
- The Maximum Operational Flexibility Alternative performs the best for California and Nevada; this is because there are zero fallowed acres and the percentage of futures with dead pool–related reductions are minimized. This would be true for PPRs in Arizona as well.

Issue 3: How would changes in dam operations affect other ITAs?

Changes in dam operations would not directly affect other ITAs in and of themselves. However, changes in dam operations could affect water levels, vegetation, fish, and wildlife; therefore, the changes could indirectly affect the value, use, or enjoyment of ITAs. General changes in vegetation, fish, and wildlife are discussed in their respective sections of this Draft EIS. Additional analysis will be incorporated if other ITAs are identified through tribal input.

Summary Comparison of Alternatives

How the alternatives affect ITAs depends on the type of ITA and other factors. For both irrigated agriculture and water deliveries in the Lower Basin, the most robust alternative depends on the interactions between the priority of water entitlements, the maximum shortages, and the percentage of futures with dead pool–related reductions. See **Section TA 18.2.8**, Summary Comparison of Alternatives, for more detailed summary comparisons of the alternatives by the type of ITA, basin, and priority group.

In general, the action alternatives are more robust than the No Action Alternative for water deliveries and irrigated agricultural land. All else equal, the action alternatives that use a variation of the priority distribution method (the Basic Coordination, Maximum Operational Flexibility, and Supply Driven [LB Priority approach] Alternatives) are more robust for more senior water entitlements; the action alternatives that use a variation of the pro rata distribution method (the Enhanced Coordination and Supply Driven [LB Pro Rata approach] Alternatives) are more robust for more junior water entitlements.

3.19 Visual Resources

3.19.1 Affected Environment

Visual resources are the physical features that make up the visible landscape, including land, water, vegetation, topography, and human-made features such as buildings, roads, utilities, and structures. They also include the response of viewers to those features.

Visual resources are important both to visitors to GCNP, Glen Canyon NRA, and Lake Mead NRA and to the Basin Tribes who use these lands for subsistence or ceremony. The Grand Canyon Protection Act of 1992 specifically calls for the conservation of visual resources, which are also a key component of federal management of these areas. GCNP, Glen Canyon NRA, and Lake Mead NRA identify management direction for visual resources as part of their general management plan, which is described in **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Lake Powell and Glen Canyon Dam

Landscape Character

The landscapes of the Lake Powell and Glen Canyon area are characterized by sweeping vistas of red rock towers, buttes, and mesas typical of the Colorado Plateau (Fenneman 1931). Navajo Sandstone and desert varnish dominate the existing landscape character with Lake Powell framing these natural features. Lake Powell has deposits of calcium carbonate, which become visible as reservoir levels decrease. At lower lake elevations, the colorful sandstone canyon walls show a white band of calcium carbonate deposits between the full reservoir elevation and the lower reservoir elevation; these deposits contrast with the natural, red-colored sandstone (see **Figure TA 19-1**, in **TA 19**, Visual Resources). Additionally, sediment deltas have formed near the inflow areas of Lake Powell as a result of sediments carried by the Colorado River and the San Juan, Dirty Devil, and Escalante Rivers, resulting in downstream-progressing deltas. These appear as expansive, deep, and eroding mud flats cut by river channels. For more information on existing landscape character, refer to **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Attraction Features

The analysis will focus on Cathedral in the Desert and Glen Canyon Dam, consistent with the 2007 Final EIS and 2024 Final SEIS. For more information on these attraction features, see **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Lake Mead to Hoover Dam

Landscape Character

The landscapes of the Lake Mead and Hoover Dam area are similar to those described for the Lake Powell area, except the adjacent landscapes are more typical of the Basin and Range region, characterized by parallel, north–south-oriented mountain ranges surrounded by nearly level, typically undrained basins (Fenneman 1931). Similar to Lake Powell, Lake Mead has deposits of calcium carbonate that contrast with the natural rock colors. For more information on existing landscape character, refer to **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Attraction Features

The analysis will focus on Hoover Dam, consistent with the 2007 Final EIS and 2024 Final SEIS. For more information on this attraction feature, see **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Hoover Dam to SIB

The landscapes from the Hoover Dam area to the SIB are characterized by arid mountain ranges and intervening desert plains associated with the Basin and Range region (Fenneman 1931). The availability of Colorado River water has resulted in large areas of irrigated landscapes, including agricultural lands in Nevada, Arizona, and California (Lower Division States), which have altered the natural landscapes. This increased water availability has introduced vivid greens associated with crops and ornamental plantings into these landscapes and has expanded the influence of the Colorado River into adjacent arid lands beyond the narrow, natural riparian corridor.

3.19.2 Environmental Consequences

Methodology

Reclamation used methods similar to those in the 2007 Final EIS and 2024 Final SEIS to analyze potential impacts on visual resources. This analysis assesses the potential effects on attraction features, the extent of the visible calcium carbonate ring, and exposure of sediment deltas at reservoir inflow areas, while incorporating the DMDU framework for this EIS. Additionally, this analysis considers the effects of expanded shoreline exposure on the area's landscape character.

Using modeling and DMDU concepts, the analysis first focuses on the percent of time during the planning window that Lake Powell would decrease below elevation 3,550 feet. At that elevation, Cathedral in the Desert and other geological attraction features—including Gregory Bridge, La Gorce Arch, and other features inundated by Lake Powell—would become visible and accessible. Based on historical averages, Lake Powell was below 3,550 feet approximately 9.9 percent of months between October 2007 and May 2025. The alternatives comparison focuses on maintaining this lake elevation for at least 10 percent of the months during the planning window. Conversely, this analysis also identifies the percentage of preferred minimum performance futures in which Lake Powell would be above 3,550 feet, resulting in less of the upstream side of Glen Canyon Dam being visible.

The potential height of the calcium carbonate ring was calculated by comparing differing reservoir elevations with the full pool elevations of Lake Powell (3,700 feet) and Lake Mead (1,221 feet) under DMDU concepts. The assessment of effects from sediment deltas and shoreline exposure considers these differing reservoir elevations and references the analysis conducted in the 2007 Final EIS.

Reclamation added two new analysis items, similar to the 2024 Final SEIS, to assess impacts on the Colorado River's landscape character and broader landscape character in the Lower Division States. This assessment is based on changes in modeled hydrologic conditions under the No Action Alternative and CCS Comparative Baseline, as well as management direction associated with the action alternatives. To assess potential changes to the landscape character along the Colorado River (between Glen Canyon Dam and Lake Mead), this analysis includes a qualitative assessment of effects associated with lower flow rates and the potential inability to conduct HFEs from Glen Canyon Dam. For more information on historic flow rates along the Colorado River, refer to **Section TA 19.2.1**, Methodology, in **TA 19**, Visual Resources, and **Section 3.3**, Hydrologic Resources**.**

The assessment of potential impacts on the broader landscape character in the Lower Division States considered changes in annual Colorado River water supplies available to these states. This identifies the extent of large-scale changes in visual character in irrigated landscapes, including changes associated with agricultural production through shortages and the potential for Lake Mead to reach dead pool–related reductions, as described in **Section 3.4**, Water Deliveries. This analysis considers and references assessment items contained in **Section 3.16**, Socioeconomics, including the effect of each alternative's proposed distribution of water on agricultural operations and the effect of increased dust generation from aridification of exposed lands, as described in **Section 3.7**, Air Quality, potentially impacting visibility and views within GCNP and other visually sensitive landscapes.

Impact Analysis Area

The visual resources impact analysis area was defined as the area within 5 miles of the Colorado River, from Lake Powell to the SIB, and full pool elevations of Lake Powell and Lake Mead. Visual effects beyond this geographic area were considered where appropriate, including the potential effects on the broader landscape character associated with potential decreased water availability for the Lower Division States. For more details on the impact analysis area, refer to **Section TA 19.2.1**, Methodology, in **TA 19**, Visual Resources.

Assumptions

- The analysis methods are consistent with the 2007 Final EIS and 2024 Final SEIS. Attraction features analyzed include Cathedral in the Desert, Glen Canyon Dam, and Hoover Dam.
- Decreasing flow rates along the Colorado River, and the potential inability to conduct HFEs from Glen Canyon Dam, would modify the river corridor's natural, visual character by limiting natural flooding processes.

- This EIS references the analysis from the 2007 Final EIS and 2024 Final SEIS regarding impacts associated with expanding sediment deltas.
- Decreasing water availability for the Lower Division States would result in large-scale changes to the visual character of irrigated landscapes, including those associated with agricultural production.

Impact Indicators

- Attraction features: Qualitative assessment describing the effects on visibility and access to Cathedral in the Desert, as well as on more of Glen Canyon Dam and Hoover Dam becoming visible on their upstream side, informed by the CRSS and DMDU analysis. Quantitative analysis identifying the percentage of preferred minimum performance futures in which Lake Powell would be below 3,550 feet (and thus Cathedral in the Desert would be visible and accessible) for at least 10 percent of the months under each alternative. Conversely, this analysis also identifies the percentage of preferred minimum performance futures in which Lake Powell would be above 3,550 feet, resulting in less of the upstream side of Glen Canyon Dam being visible.
- Calcium carbonate rings: Comparison of modeled heights (in feet) of the calcium carbonate rings at Lake Powell and Lake Mead under each alternative, considering the CRSS and DMDU analyses.
- Exposed shoreline and sediment deltas: Qualitative assessment referenced from the 2007 Final EIS and 2024 Final SEIS, considering differing reservoir elevations under each alternative, to assess receding shorelines and formation of sediment deltas resulting from lower reservoir elevations.
- Colorado River landscape character: Qualitative description of the effect associated with proposed flow rates and the potential to conduct HFEs from Glen Canyon Dam under each alternative, considering modeling presented in **Section 3.9**, Vegetation Including Special Status Species; **Section 3.5**, Geomorphology and Sediment; **Section 3.14**, Recreation; and **Section 3.7**, Air Quality.
- Broader landscape character: Qualitative description of the effects associated with potential decreases in water availability for the Lower Division States on the broader landscape character. This includes considering modeling associated with potential changes to crop production resulting from proposed distribution of water, as described in **Section 3.16**, Socioeconomics, as well as the potential for Lake Mead to reach dead pool–related reductions as described in **Section 3.4**, Water Deliveries.

Issue 1: How would management of reservoir elevations affect visibility of attraction features?

The assessment of impacts on landscape character associated with the elevations of Lake Powell considers two concepts. The first part of the assessment considers the positive impact on landscape character that occurs when Lake Powell is below 3,550 feet and Cathedral in the Desert (and other attraction features inundated by Lake Powell) is visible and accessible. For more information on this portion of this issue, refer to **Section TA 19.2.2**, Visibility of Attraction Features, in **TA 19**, Visual Resources.

The second part of the analysis focuses on keeping the Lake Powell water levels high, which reduces the visibility of Glen Canyon Dam, specifically when above 3,550 feet. As reservoir levels decrease, exposing more of the dam's concrete structure, the dam's effect on the area's landscape character would increase, further dominating the landscape character. As shown in **Figure TA 19-3** in **TA 19**, Visual Resources, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in more preferred minimum performance futures where less of the upstream side of Glen Canyon Dam is visible due to being "blocked" by water. Lower flows could keep Lake Powell at higher elevations under the Enhanced Coordination and Maximum Operational Flexibility Alternatives compared with the CCS Comparative Baseline, No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative .

As shown in **Figure TA 19-4** in **TA 19**, Visual Resources, comparing DMDU modeling with the driest historic 10-year average flows, the CCS Comparative Baseline, No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative would require higher flows to maintain similar elevations, which would increase the vulnerability of meeting a preferred minimum performance future under those alternatives. Specifically, those alternatives would be more vulnerable than the Enhanced Coordination and Maximum Operational Flexibility Alternatives, with over 75 percent of the historic hydrologic conditions resulting in the potential for Lake Powell to decrease below 3,550 feet for 10 percent or more of months during the planning period. Approximately 25 percent of the historic hydrological conditions under the Enhanced Coordination Alternative, and approximately 50 percent under the Maximum Operational Flexibility Alternative, would result in conditions where Lake Powell could decrease below 3,550 feet for 10 percent or more of the planning period.

Based on modeling scenarios that show lake levels within Lake Powell and Lake Mead, impacts associated with the visibility of Hoover Dam would be similar to those associated with Glen Canyon Dam under the CCS Comparative Baseline and the No Action, Enhanced Coordination, and Maximum Operational Flexibility Alternatives. Under the Basic Coordination Alternative and Supply Driven Alternative (65 percent), based on managing higher reservoir levels in Lake Mead than in Lake Powell, less of the upstream side of Hoover Dam would be visible, with comparatively more of the upstream side of Glen Canyon Dam being visible, as described above. Therefore, as Lake Mead reservoir levels decrease, exposing more of the dam's concrete structure, its effect on the area's landscape character would increase and further dominate the landscape character.

Issue 2: How would management of reservoir elevations affect landscape character, including visibility of calcium carbonate rings, exposed shoreline, and sediment deltas?

The assessment of impacts on landscape character along Lake Powell and Lake Mead was based on determining the percentage of futures at different reservoir levels, compared with the full pool elevation. This difference in reservoir elevations creates white-colored calcium carbonate rings as well as generating larger sediment deltas and exposing more shoreline. The lower the lake levels become, the more the impacts on landscape character associated with calcium carbonate rings, exposed shoreline including garbage and refuse, and sediment deltas would increase. To compare alternatives, the assessment focused on whether calcium carbonate rings would exceed historic maximums at any time during the planning period.

For Lake Powell, the tallest calcium carbonate ring, which occurred in February 2023, was 179 feet tall. As shown in **Figure TA 19-5**, in **TA 19**, Visual Resources, the CCS Comparative Baseline and the No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative would result in more futures where the calcium carbonate rings would exceed the historical maximum during the modeling period. Only 18 percent, 16 percent, 16 percent, and 13 percent of futures under these alternatives, respectively, would result in calcium carbonate rings being less than 175 feet tall for all the months of modeling. The Enhanced Coordination and Maximum Operational Flexibility Alternatives would increase these values to 51 percent and 38 percent. Expanding the threshold to 200-foot-tall calcium carbonate rings, as shown in **Figure TA 19-6**, in **TA 19**, Visual Resources, the CCS Comparative Baseline, No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative would maintain the calcium carbonate rings below this height for all months in only 23 percent, 20 percent, 25 percent, and 24 percent of the futures, respectively. Comparatively, under the Enhanced Coordination and Maximum Operational Flexibility Alternatives, 82 percent and 87 percent of the futures, respectively, would result in calcium carbonate rings being under 200 feet for all months.

For Lake Mead, the tallest calcium carbonate ring, which occurred in July 2022, was 180 feet. As shown in **Figure TA 19-7**, in **TA 19**, Visual Resources, the CCS Comparative Baseline and the No Action Alternative would result in more futures where calcium carbonate rings would exceed the historical maximum during the modeling period, with only 13 percent and 6 percent of futures under these respective alternatives resulting in calcium carbonate rings being less than 175 feet tall for all the months of modeling. Under the Basic Coordination Alternative, Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative, these percentages would increase to 30 percent, 29 percent, 32 percent, and 40 percent, respectively. Expanding the threshold to 200-foot-tall calcium carbonate rings, as shown in **Figure TA 19-8** in **TA 19**, Visual Resources, under the CCS Comparative Baseline and the No Action Alternative the calcium carbonate rings would remain below this height for all months in only 22 percent and 12 percent of the futures, respectively. Comparatively, the Basic Coordination Alternative, Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative would result in 41 percent, 44 percent, 50 percent, and 52 percent of the futures, respectively, resulting in calcium carbonate rings under 200 feet for all months.

As described in the 2007 Final EIS, sediment deltas would continue to build up over time and would be visible as the reservoir elevations decrease, including under the No Action Alternative. The expanding sediment deltas would become populated by vegetation, including tamarisk, which would introduce into the landscape bright greens that would contrast with the arid landscapes adjacent to Lake Powell and Lake Mead. Additionally, the receding shorelines would expose garbage and refuse, which would diminish the area’s landscape character. The lower the lake levels become, the more the impacts on landscape character associated with calcium carbonate rings, exposed shoreline including garbage and refuse, and sediment deltas would increase.

The calcium carbonate ring, exposed shoreline including garbage and refuse, and sediment deltas would modify the landscape character along the edge of Lake Powell. These modifications would be visible for motorists on Utah State Route 95, boaters on Lake Powell, recreationists at developed and undeveloped recreation areas, and hikers on trails adjacent to Lake Powell. Similarly, the calcium carbonate ring, exposed shoreline including garbage and refuse, and sediment deltas would modify the landscape character along the edge of Lake Mead; these modifications would be visible for motorists on US Highway 93 (between Boulder City, Nevada, and the Hoover Dam), boaters on Lake Mead (including visitors to Overton Beach and Pearce Ferry), and hikers on trails adjacent to Lake Mead.

Issue 3: How would management of releases from Glen Canyon Dam affect landscape character along the Colorado River?

The No Action Alternative and the CCS Comparative Baseline would include lowering releases from Glen Canyon Dam as Lake Powell elevations decrease; this would result in releases as low as 7.0 maf when elevations drop below 3,525 feet. Since neither the No Action Alternative nor the CCS Comparative Baseline would reduce releases from Glen Canyon Dam under 7.0 maf, including if Lake Powell drops below power pool but remains above dead pool, there would be minor, incremental impacts on the landscape character along the Colorado River, including through the Grand Canyon. The current trend of increasing bank armoring associated with expanding riparian vegetation areas (including tamarisk) would continue under the No Action Alternative and CCS Comparative Baseline. If the elevation of Lake Powell were to drop below dead pool, flows from Glen Canyon Dam could dramatically decrease, resulting in more extensive impacts on the landscape character, including the appearance of river features not visible under current conditions. Additionally, the positive influence of the moving, turbulent Colorado River adds to the existing landscape character, which would be degraded if releases from Glen Canyon Dam were dramatically reduced. The No Action Alternative would result in relatively short and few HFE releases, providing fewer opportunities for sand bar volumes to increase compared with the CCS Comparative Baseline, which would result in longer and more frequent HFE releases with more opportunities for increased sand bar volumes.

The Basic Coordination Alternative would result in impacts similar to those under the No Action Alternative and CCS Comparative Baseline, since it includes a similar range of releases from Glen Canyon Dam, but would include an increased number of futures where HFEs are conducted. The Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative would include lower releases—as low as 4.7 maf, which is lower than historical minimum flows. Lower releases from Glen Canyon Dam would result in less water flowing along the Colorado River (and through the Grand Canyon), which could increase existing trends of bank armoring associated with more extensive riparian vegetation, including tamarisk. Lower releases also could limit the number of times an HFE could be triggered from Glen Canyon Dam; a trigger would only occur when the HFE furthers maintenance of target reservoir elevations.

The Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in the greatest number of futures where HFEs are conducted. These lower flows may also result in the appearance of river features not visible under current conditions and less movement of the river's natural sandbars. If yearly elevations facilitate releases of 7.0 maf or more under the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative, the impacts under these alternatives would be similar to those described under the No Action Alternative and CCS Comparative Baseline as the lower releases from Glen Canyon Dam would be avoided. If the elevation of Lake Powell were to drop below dead pool, flows from Glen

Canyon Dam could dramatically decrease, resulting in impacts similar to those described under the No Action Alternative and CCS Comparative Baseline.

For more information on the impacts on riparian vegetation, refer to **Section 3.9**, Vegetation Including Special Status Species; for impacts associated with sand bars, including their volume, refer to **Section 3.5**, Geomorphology and Sediment; and for impacts on recreation, including the visibility of river features, refer to **Section 3.14**, Recreation.

Issue 4: How would management of water availability for the Lower Division States affect landscape character?

Since the No Action Alternative would include minor (0.6 maf) adjustments to the distribution of water for Arizona and Nevada (but no adjustments for California) based on lowering Lake Mead elevations, there would initially be a limited incremental effect on irrigated landscapes, including those in agricultural use. If elevations in Lake Mead were to drop to dead pool (895 feet), flows from Lake Mead would dramatically decrease, resulting in lower water deliveries than currently allocated, affecting all three Lower Division States. As described in **Section 3.4**, Water Deliveries, the No Action Alternative would result in the most futures where dead pool–related reductions may be reached during the modeling period. Depending on the duration of these decreased water deliveries, the character of irrigated and agricultural landscapes within the Lower Division States would be modified through aridification of these areas; this would diminish the vivid greens associated with crops and ornamental plantings. The influence of the Colorado River on adjacent lands would narrow as these areas transition to their natural, arid condition. This would result in large-scale changes to the landscape character compared with the existing condition. The aridification of these lands could also result in more exposed soil, generating fugitive dust affecting visibility within the region, including from GCNP and other highly valued viewsheds. For more details on the impacts related to fugitive dust, please see **Section 3.7**, Air Quality.

The following alternatives all include shortages designed to avoid reaching dead pool, temper the impacts on the character of irrigated and agricultural landscapes within the Lower Division States, and avoid more extensive impacts if Lake Mead reached dead pool. If Lake Mead reaches dead pool elevation during the planning period, impacts for all alternatives would be similar to those described under the No Action Alternative.

The CCS Comparative Baseline would include a series of water supply adjustments for the Lower Division States based on lower elevations of Lake Mead. If water levels in Lake Mead drop below 1,075 feet, effects similar to those described under the No Action Alternative would occur, with conservation measures tempering these effects. As Lake Mead approaches dead pool, to avoid a dramatic decrease in water releases from Hoover Dam affecting all three Lower Division States, more reductions (up to 1.38 maf) could occur. These reductions to avoid reaching dead pool would temper the impacts on the character of irrigated and agricultural landscapes within the Lower Division States, as described under the No Action Alternative.

The Basic Coordination Alternative would have impacts similar to those under the No Action Alternative, as there would be adjustments to the distribution of water for Arizona and Nevada, but no adjustments for California based on lowering Lake Mead elevations. As the Lake Mead elevation drops below 1,160 feet, shortages would begin; they would increase to 1.48 maf when Lake Mead is below 1,110 feet. Due to increased shortages under this alternative, the Basic Coordination Alternative would result in the second most futures where dead pool–related reductions may be reached during the modeling period, as described in **Section 3.4**, Water Deliveries. Under the Enhanced Coordination Alternative, there is a potential for greater shortages than under the No Action Alternative, CCS Comparative Baseline, and Basic Coordination Alternative, with shortages (up to 3.0 maf) being distributed pro rata among mainstream lower Colorado River water users independent of state. These shortages would occur in all three Lower Division States and incrementally affect irrigated landscapes, including those in agricultural use, based on the extent of the shortage. As described in **Section 3.4**, Water Deliveries, the Enhanced Coordination Alternative would result in the second least number of futures where dead pool–related reductions may be reached during the modeling period.

Under the Maximum Operational Flexibility Alternative, there is a potential for greater shortages than under the CCS Comparative Baseline and the Enhanced Coordination, No Action, and Basic Coordination Alternatives, with shortages being based on priority. These shortages would occur based on the total system effective storage and capacity, as described in **Section 2.7.1.1**, Shortage Conditions, with shortages up to 4.0 maf. These shortages would occur in all three Lower Division States and incrementally affect irrigated landscapes, including those in agricultural use, based on the extent of the shortage. As described in **Section 3.4**, Water Deliveries, the Maximum Operational Flexibility Alternative would result in the least number of futures where dead pool–related reductions may be reached during the modeling period

Under the Supply Driven Alternative, there is a potential for larger shortages (up to 2.1 maf) than under the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives, with shortages being distributed based on priority within a state or pro rata within that state as described in **Section 2.8.1.1**, Shortage Conditions. If water levels in Lake Mead drop below 1,145 feet, effects similar to those described under the No Action Alternative are anticipated, with conservation measures tempering these effects. As lake levels continue to drop toward 1,000 feet, all three states would receive less water from the Colorado River under this alternative through proposed shortages, up to 2.1 maf, and conservation measures.

For more information on the impacts on agricultural operations, refer to **Section 3.16**, Socioeconomics, and for more information on the specific, state-level water deliveries, refer to **Section 3.4**, Water Deliveries.

Summary Comparison of Alternatives

In general, alternatives that facilitate higher reservoir elevations, maintain higher flows along the Colorado River, including through Grand Canyon, and support full water deliveries to the Lower Division States would result in the lowest impacts on visual resources and landscape character. While some users may prefer lower lake levels in Lake Powell, to allow Cathedral in the Desert and other attraction features inundated by Lake Powell to be visible and accessible, in general higher water levels would result in lower impacts on landscape character because there would be shorter calcium carbonate rings, less exposed shoreline (including garbage and refuse), and smaller sediment deltas.

During wet hydrologic conditions, the range of alternatives would generally produce conditions where lake levels and flows along the Colorado River would result in minimal impacts on landscape character.

Under drier conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would facilitate more futures with higher reservoir elevations and lower flows along the Colorado River to minimize the risk of reaching dead pool. These alternatives also include larger water delivery shortages to the Lower Division States, which were designed to avoid reaching dead pool. These alternatives would result in shortages up to 3.0 maf and 4.0 maf, respectively, which would incrementally affect irrigated landscapes, including those in agricultural use, as shortages occur.

The CCS Comparative Baseline, No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative would result in the most futures where landscape character is affected by lower water levels in Lake Powell and higher flows along the Colorado River, which would increase the risk of reaching dead pool. Based on management to keep water levels higher in Lake Mead than Lake Powell, under the Basic Coordination Alternative and Supply Driven Alternative, impacts associated with lower Lake Mead reservoir levels would not occur and impacts would be similar to those under the Enhanced Coordination and Maximum Operational Flexibility Alternatives.

The CCS Comparative Baseline and the No Action and Basic Coordination Alternatives would include smaller shortages in water deliveries to the Lower Division States—0.6 maf, 1.38 maf, and 1.48 maf, respectively—resulting in limited initial effects on irrigated landscapes compared with the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative. If dead pool is reached, however, the character of irrigated and agricultural landscapes within the Lower Division States would be more dramatically modified through aridification of agricultural and other irrigated landscapes. The Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative would result in the least number of futures where dead pool-related reductions may be reached during the planning period.