BUREAU OF RECLAMATION

Implementation Effects of New Area and Capacity Surveys for Lake Mohave and Lake Havasu

Lake Mohave & Lake Havasu: Nevada, Arizona, and California

Lower Colorado Basin Region

U.S. Department of the Interior January 30, 2026

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Cover Photo: Parker Dam Forebay (Lake Havasu) on the Arizona & California border. Photograph taken by Erin Orozco-Whitaker, January 28, 2023.

Disclaimer

Executive Summary

The Bureau of Reclamation (Reclamation) funded a study to develop new topo-bathymetric surveys on Lake Mohave and Lake Havasu. These surveys updated area and capacity tables (ACAPs), replacing data from 1949 and 1957, respectively. The survey data were collected between November 2021 and June 2022, as part of a larger study that collected bathymetric data from below Hoover Dam to the Southerly International Boundary (SIB) with Mexico.

The study updated storage capacity and surface area for Lake Mohave and Lake Havasu using the new survey data. Lake Mohave's available live storage is 1,873,650 acre-feet (af) between elevation 647.00 feet (top of spillway gates) and 533.39 feet (lowest outlet). Dead storage (capacity below the lowest intake structure) is 13,520 af below elevation 533.39 feet. Lake Havasu's available live storage (capacity above dead storage) is 570,250 af between elevation 450.00 feet (top of spillway gates) and 400.00 feet (lowest outlet). Dead storage is 20,010 af below elevation 400.00 feet (lowest outlet). Lake Mohave surface area at 655.00 feet (top of dam) is 29,600 acres and the area at 647.00 feet (top of spillway gates) is 28,890 acres. Lake Havasu surface area at 455.00 feet (top of dam) is 20,690 acres and the area at 450.00 feet (top of spillway gates) is 19,810 acres.

Elevations are referenced to Reclamation Project Vertical Datum (RPVD) for each respective dam. To convert elevations from each project's datum to the standard North American Vertical Datum of 1988 (NAVD88) use the following equations:

RPVD Davis elevation (feet) = NAVD88 elevation (feet) - 3.39 feet.
RPVD Parker elevation (feet) = NAVD88 elevation (feet) - 2.72 feet.

Reclamation modelers performed a sensitivity analysis and evaluated the impacts of the updated ACAPs tables in Reclamation's basin-wide deterministic/probabilistic operational and planning models, including the Colorado River Mid-Term modeling system (CRMMS) and the Colorado River Simulation System (CRSS). The sensitivity analysis results indicated minimal impacts to Lake Mead and Lake Powell reservoir operations projections. Since Lake Mohave and Lake Havasu are operated to elevation guide curves, there are no impacts to elevations and only minimal impacts to other elements of the water balance.

In summary, the new bathymetry at Lake Mohave and Lake Havasu provides a better understanding of the actual storage capacity and surface area at these two reservoirs. The updated and improved data will be implemented operationally in record-keeping and in operational modeling, to provide the Colorado River Basin managers and interested parties with data and model projections that incorporate the best available information.

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Acronyms and Abbreviations

2007 Interim Guidelines	2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead
24MS	CRMMS: 24-Month Study
ACAPs	Area and Capacity Tables
af	acre-feet
Basin	Lower Colorado River Basin
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems
CBRFC	Colorado Basin River Forecast Center
CRMMS	Colorado River Mid-term Modeling System
CRMMS-ESP	CRMMS Ensemble Streamflow Prediction mode
CRSS	Colorado River Simulation System
CY	Calendar Year
EOCY	end of calendar year
EOWY	end of water year
ESP	Ensemble Streamflow Prediction
kaf	thousand acre-feet
LiDAR	Light detection and ranging
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
MBES	Multi-beam echo sounder
NA	Data not available
NFM	Natural Flow Model
Reclamation	Bureau of Reclamation
ROD	Record of Decision
RPVD	Reclamation Project Vertical Datum
SEIS	Supplemental Environmental Impact Statement
SIB	Southerly International Boundary with Mexico
WY	water year

1. Introduction

Reservoir area and capacity tables (ACAPs) are essential to reservoir management by providing critical reservoir data for Reclamation’s operations and planning models and serve as a basis for computing the main factors of the water/mass balance at each reservoir. Developed through comprehensive reservoir surveys, these tables enable water managers to have precise information on reservoir storage capacity and surface area, at different reservoir elevation levels, when running system models and providing briefings on current system conditions.

The objective of this study is to understand the impacts of implementing new ACAPs tables coming out of new reservoir surveys on operations and decision making. This sensitivity analysis includes the evaluation of impacts to storage and surface area as compared to the current ACAPs tables in operational use. Figure 1 below shows the study area and the location of Lake Mohave and Lake Havasu in the Lower Colorado Basin Region.

1.1 Background

The reservoirs in the Lower Colorado River Basin (Basin) serve as a crucial resource for water management in the southwestern United States. Characterized by its arid climate, the Basin receives minimal tributary runoff entering the mainstem of the Colorado River, and experiences infrequent precipitation events. Consequently, the region depends heavily on the controlled management of the Colorado River system to maintain habitability and productivity of the adjacent lands.

Reclamation is tasked with implementing the water master role within the Basin on behalf of the Secretary of the Interior. This includes the management of two mainstem reservoirs, Lake Mohave and Lake Havasu (Figure 1). Lake Mohave was formed in 1951 with the construction of Davis Dam. This reservoir is located approximately 67 miles downstream from Hoover Dam and plays a vital role in regulating the flow of the Colorado River between Hoover and Parker Dams. Similarly, Lake Havasu was created in 1938 with the construction of Parker Dam, and it is located approximately 88 miles south of Davis Dam and 136 miles from Hoover Dam. It serves as a crucial water storage project and diversion point for the Metropolitan Water District of Southern California and the Central Arizona Project.

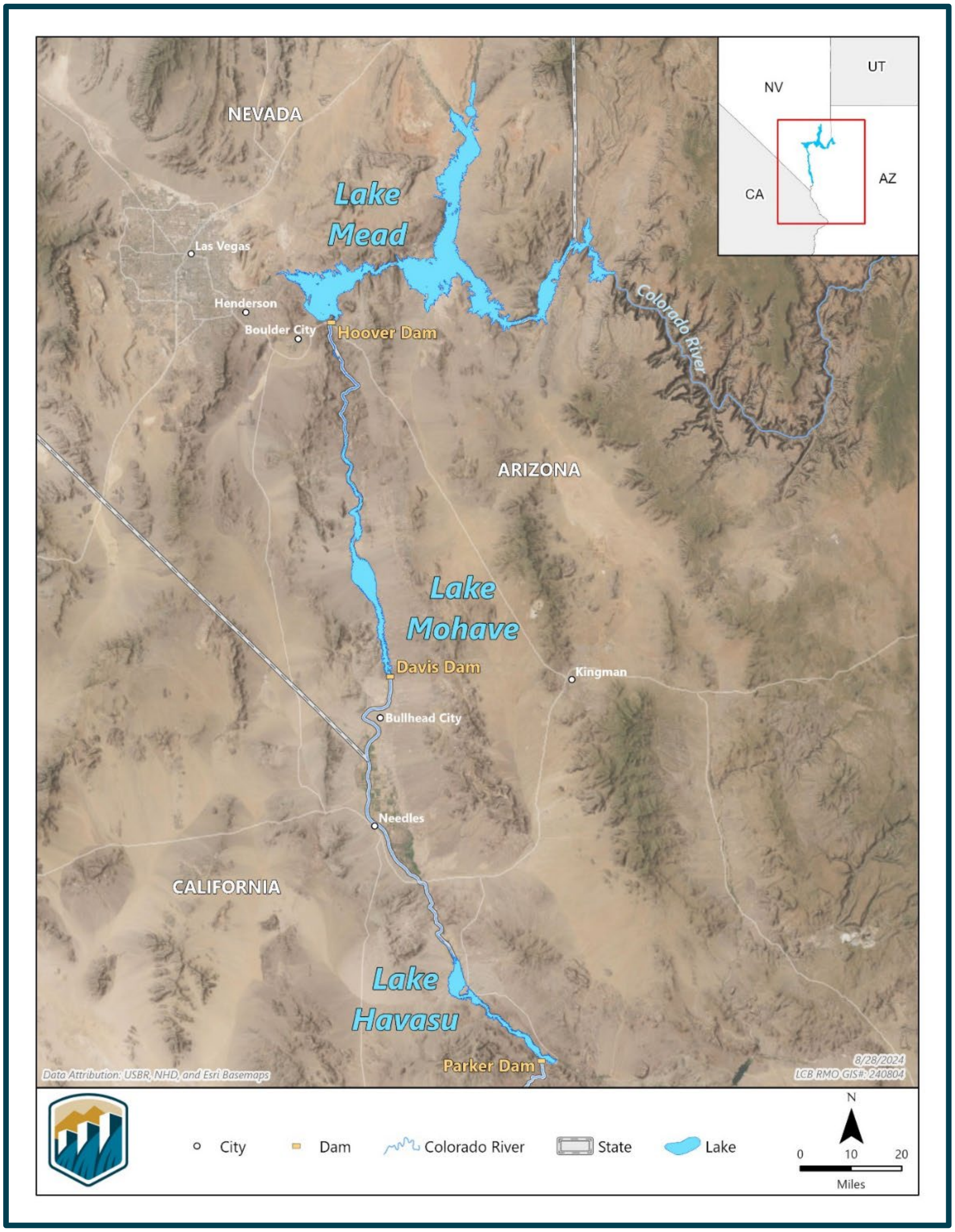

Figure 1 - Map of the study area with Lake Mead, Lake Mohave and Lake Havasu (M. Potter, Reclamation).

Reclamation conducted detailed surveys to compile ACAPs for the associated reservoirs. These surveys were finalized in 1949 for Lake Mohave and in 1957 for Lake Havasu. Periodically conducting new surveys is important to consider as equipment and survey technology progresses, and also to monitor reservoir sedimentation. A 2001 sedimentation survey of Lake Mead revealed that the construction of Glen Canyon Dam on the Colorado River, near the Arizona-Utah border in 1963, significantly altered the expected life span of Hoover Dam by eliminating approximately two-thirds of the sediment-contributing drainage area previously affecting Lake Mead. Due to the findings of the Lake Mead survey, sedimentation in the lower basin reservoirs has not been a motivating factor for frequent reservoir surveys of Lake Mohave and Lake Havasu (Reclamation, 2008).

Low sedimentation rates in Basin reservoirs aside, the length of time since the last reservoir surveys, and scientific advances, warranted new reservoir surveys. In 2022, Reclamation performed new topo-bathymetric surveys to provide up-to-date data using state of the art scientific survey methods.

2. Methodology

2.1 Data Collection and Vertical Datums

A detailed topo-bathymetric survey of the Lower Colorado River from Hoover Dam to the SIB was conducted in Spring 2022 using vessel-based Multi Beam Echo Sounder (MBES) methods and combined with topo-bathymetric Light Detection and Ranging (LiDAR) techniques in Fall 2021. The specifics of data acquisition and assessment are thoroughly documented in reports submitted to Reclamation, forming the basis for the updated ACAPs tables and the rectification of historical vertical datums (Reclamation, 2022).

The topo-bathymetric surveys, conducted by RiverRestoration, LLC, enabled acquisition of highly accurate topographic and bathymetric data for Lake Mohave and Lake Havasu, extending from the lakebed to elevations beyond the top of the spillway gates. Table 1 summarizes the source of the data at different elevation intervals.

Table 1 - Description of Data Sources for Surface Area and Capacity Tables (Source: Reclamation, 2022)

Reservoir	Elevation Interval	Data Source
Lake Havasu	below 420 feet	2022 MBES bathymetric survey[1]
	420 feet to 450 feet	Derived from overlapping data from the 2021 topo-bathymetric LiDAR and 2022 MBES bathymetric surveys[2]
	above 450 feet	2021 topo-bathymetric LiDAR survey
Lake Mohave	Below 600 feet	2022 MBES bathymetric survey[1]
	600 feet to 630 feet	Derived from overlapping data from the 2021 topo-bathymetric LiDAR and 2022 MBES bathymetric surveys[2]
	Above 630 feet	2021 topo-bathymetric LiDAR survey

Reservoir surface area and capacity relationships were calculated using ESRI's storage capacity tool within the Spatial Analyst Supplemental Toolbox in ArcMap. This tool was used to calculate the storage volume and surface area at 0.1-foot elevation intervals. Linear interpolation was used to create tables representing volumes at 0.01-foot intervals.

The surveys were completed using the North American Vertical Datum of 1988 (NAVD88); and the data was provided in NAVD88 as well as other vertical datums used by Reclamation, the National Geodetic Vertical Datum of 1929 (NGVD 29) and the dam-specific Reclamation Project Vertical Datum (RPVD) used during the construction of the dam and for elevation measurements throughout the period of record. To this day, Reclamation uses the RPVD datum for reservoir elevation data on the Colorado River mainstem. The survey data recorded in NAVD88 were used to calibrate and verify specific shifts to convert elevation data to the RPVD.

[1] Includes estimates of bathymetry at dam forebay and interpolation of data between areas of data collection.
[2] Overlapping data were used as check of survey accuracy between multiple data collections. All data were compiled into one DEM dataset for the purpose of area and capacity calculations.

The survey included four historic Reclamation monuments at Parker and Davis Dams to determine a vertical height shift for the 2021 and 2022 topo-bathymetric data. The height shift for Lake Mohave, used in the Elevation-Storage curves and data, is based on the surveyed monuments and is represented by the following elevation conversion equation:

Equation 1: RPVD Davis elevation (feet) = NAVD88 elevation (feet) - 3.39 feet.

Similarly, the height shift for Lake Havasu, used in the Elevation-Storage curves and data, is based on the surveyed monuments and is represented by this elevation conversion equation:

Equation 2: RPVD Parker elevation (feet) = NAVD88 elevation (feet) - 2.72 feet.

In 2023, Reclamation's Yuma Area Office Survey Crew conducted peer review surveys and verified the vertical datum conversions at both dams. These peer review surveys will be documented in a Memorandum to Files in a parallel process to this study.

2.2 Reclamation Modeling

Reclamation manages and maintains multiple basin-wide reservoir operations models. These models are developed using the RiverWare modeling software. The RiverWare platform was created by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado, Boulder (Zagona et al., 2001). The operations models discussed in this report include the following:

- Gain/Loss Model
- CRMMS: 24-Month Study
- CRMMS: ESP
- Natural Flow Model
- CRSS

All models simulate the operational dynamics of the primary reservoirs within the Colorado River system, providing projected operational data for Reclamation's principal facilities. The output variables encompass reservoir storage, elevation, releases, energy generation, streamflow at various system points, and diversions/return flows from water users.

In order to evaluate the impacts of using the new ACAPs tables on Reclamation's hydrologic models, a sensitivity analysis was conducted on each of the models listed above. The model outputs using the current ACAPs tables were compared against those using the new survey ACAPs tables. This analysis was done to understand potential impacts to operational decision making. Figure 2 below summarizes how three of Reclamation's primary models, for providing system projections and risk outlook, differ from one another structurally.

	Colorado River Mid-term Modeling System (CRMMS)		CRSS
	24-Month Study Mode *(Manual Mode)*	Ensemble Mode *(Rule-based Mode)*	
Primary Use	AOP tier determinations and projections of current conditions	Risk-based operational planning and analysis	Long-term planning, comparison of alternatives
Simulated Reservoir Operations	Operations input manually	Rule-driven operations	
Probabilistic or Deterministic	Deterministic – single hydrologic trace	Deterministic OR Probabilistic 35 (or more) hydrologic traces	Probabilistic – 100+ traces
Time Horizon (years)	1 - 2	1 - 5	1 - 50
Upper Basin Inflow	Unregulated forecast, 1 trace	Unregulated ESP forecast, 35 traces	Natural flow; historical, paleo, or climate change hydrology
Upper Basin Demands	Implicit, in unregulated inflow forecast		Explicit, 2016 UCRC assumptions
Lower Basin Demands	Official approved or operational		Developed with LB users

Figure 2 - Mid-term and Long-term Model Structural Comparison

2.2.1 Reservoir Mass Balance

The Colorado River models use a mass balance approach, which accounts for all water entering, stored in, and leaving the system. Reservoir outflow, pool elevation, diversions, return flows, and bank storage are explicitly modeled. Reservoir storage and evaporation are derived using the ACAPs tables. The storage is derived directly from the elevation-capacity table, and the evaporation is computed based on surface area and a monthly evaporation coefficient. The surface area used to compute evaporation is derived directly from the elevation-surface area table.

The residual of the mass balance equation is referred to as the intervening flow (also referred to as side inflow or gain/loss). This variable represents the sum of tributary inflows, precipitation/runoff, river reach evapotranspiration, and any groundwater losses or gains. This term also incorporates any potential error from other components of the mass balance models.

The generic mass balance formula is as follows: Change in storage = $\sum$ Inflows – $\sum$ Outflows

The mass balance equations can be solved to determine the intervening flow for Lake Mohave and Lake Havasu. Equation 3 solves for the intervening flow for the reach between Hoover Dam and Davis Dam while Equation 4 solves for the intervening flow for the reach between Davis Dam and Parker Dam. Evapotranspiration in the river between two sites is not explicitly modeled and is instead lumped in as part of the total intervening flow.

Equation 3: $\text{Intervening Flow}_{\text{Hoover to Davis}} = O_D + \Delta S + D + E_{Mohave} - O_{Hvr} - R$

Where:
O_D is the outflow from Davis Dam in acre-feet
ΔS is the change in Lake Mohave Storage in acre-feet
D is the sum of all diversions between Hoover Dam to Lake Mohave in acre-feet
E_{Mohave} is the total evaporation from Lake Mohave in acre-feet
O_{Hvr} is the outflow from Hoover Dam in acre-feet
R is the total return flow to the river between Hoover Dam and Lake Mohave in acre-feet

Equation 4: $\text{Intervening Flow}_{\text{Davis to Parker}} = O_P + \Delta S + D + E_{Havasu} - O_D - R$

Where:
O_P is the outflow from Parker Dam in acre-feet
ΔS is the change in Lake Havasu Storage in acre-feet
D is the sum of all diversions between Davis Dam and Lake Havasu in acre-feet
E_{Havasu} is the total evaporation from Lake Havasu in acre-feet
O_D is the outflow from Davis Dam in acre-feet
R is the total return flow to the river between Davis Dam and Lake Havasu in acre-feet

2.2.2 Gain/Loss Model

The Gain/Loss model operates on a monthly time-step to compute the historical intervening flow for the river spanning from Glen Canyon Dam to the Northerly International Boundary with Mexico. This model integrates historical water usage, stream gage data, and reservoir operations data to determine the monthly intervening flow, using the mass balance approach described above. The derived intervening flow is subsequently utilized to develop the intervening flow projections for use in CRMMS. In the CRMMS: 24-Month Study, a five-year running average is currently used to project future intervening flows. In CRMMS-ESP, the 30-year record of intervening flows is used in an index sequential method (Ourda et al., 1997) to project intervening flows.

2.2.3 CRMMS Modeling System

CRMMS functions as a mid-term, basin-wide model capable of simulating operations with either a single hydrologic inflow forecast or an ensemble of hydrologic inflow forecasts. When executed with a single two-year forecast, incorporating manually input operations, it is referred to as CRMMS: 24-Month Study. Conversely, when CRMMS is deployed with an ensemble of forecasts extending over a five-year period, it is designated as CRMMS-ESP.

2.2.3.1 CRMMS-24-Month Study

CRMMS: 24-Month Study, more commonly known as the 24-Month Study (24MS), is a basin-wide, mid-term, deterministic model that runs on a monthly timestep, with an official simulation period of up to two years. The model uses a “most probable” unregulated inflow forecast, provided by the Colorado Basin River Forecast Center (CBRFC), for the Upper Colorado Basin Region reservoirs. The CBRFC’s forecasts rely on the Ensemble Streamflow Prediction (ESP) method to generate multiple forecast streamflow time series. Each time series is developed using initial model conditions for soil moisture/snowpack and historical climatology. The end-product of the ESP modeling is a monthly unregulated inflow forecast for each of the upper basin reservoirs for the current water year (WY). The “most probable” unregulated inflow forecast provided by the CBRFC statistically would be exceeded 50% of the time. The 24MS is run and published monthly to provide regular updates on projected basin-wide conditions and operations using the “most probable” unregulated inflow forecast, water use schedules, and reservoir operations. In addition to the “most probable” run, “probable minimum” and “probable maximum” 24MS runs are published four times a year under normal circumstances.

The “probable maximum” unregulated inflow forecast reflects a wet scenario which statistically would be exceeded 10% of the time. The “probable minimum” unregulated inflow forecast reflects a dry scenario which statistically would be exceeded 90% of the time. There is approximately an 80% likelihood that future conditions will fall inside the range of projected elevations between the probable minimum and probable maximum scenario in the first simulation year. For the second year of the model run, the “probable maximum” and “probable minimum” runs represent the 25th and 75th exceedance probabilities, respectively.

Under the current operating guidelines for Lake Powell and Lake Mead, the August “most probable” 24MS projections of the end of calendar year (EOCY) elevations of Lake Mead and Lake Powell are used to determine the lower basin operating condition for the following calendar year (CY) and the Powell release volume for the following WY. The April “most probable” 24MS projections of the end of water year

(EOWY) elevations of Lake Mead and Lake Powell are used to determine whether an adjustment to the Lake Powell WY release will be made under certain operating conditions.

A summary of the coordinated operations policy for Lake Powell and Lake Mead under the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (2007 Interim Guidelines) and the 2024 Supplemental Environmental Impact Statement (SEIS) for Near-term Colorado River Operations Record of Decision (ROD) is shown below in Figure 3. With this in mind, there is some sensitivity to the analysis performed in this report using historical model runs and whether an update to area and capacity surveys and intervening flow would have resulted in a different operating condition/tier at Lake Powell or Lake Mead. A change in operating condition at Lake Mead could have resulted in a different shortage volume imposed on the Lower Division states (and Mexico under IBWC Minute No. 323). Similarly, a change in operating tiers at Lake Powell could have resulted in a different WY release volume as shown in Figure 3. A detailed description of the coordinated operations and shortage policies can be found in Section 2 and Section 6 of the 2007 Interim Guidelines (Reclamation, 2007).

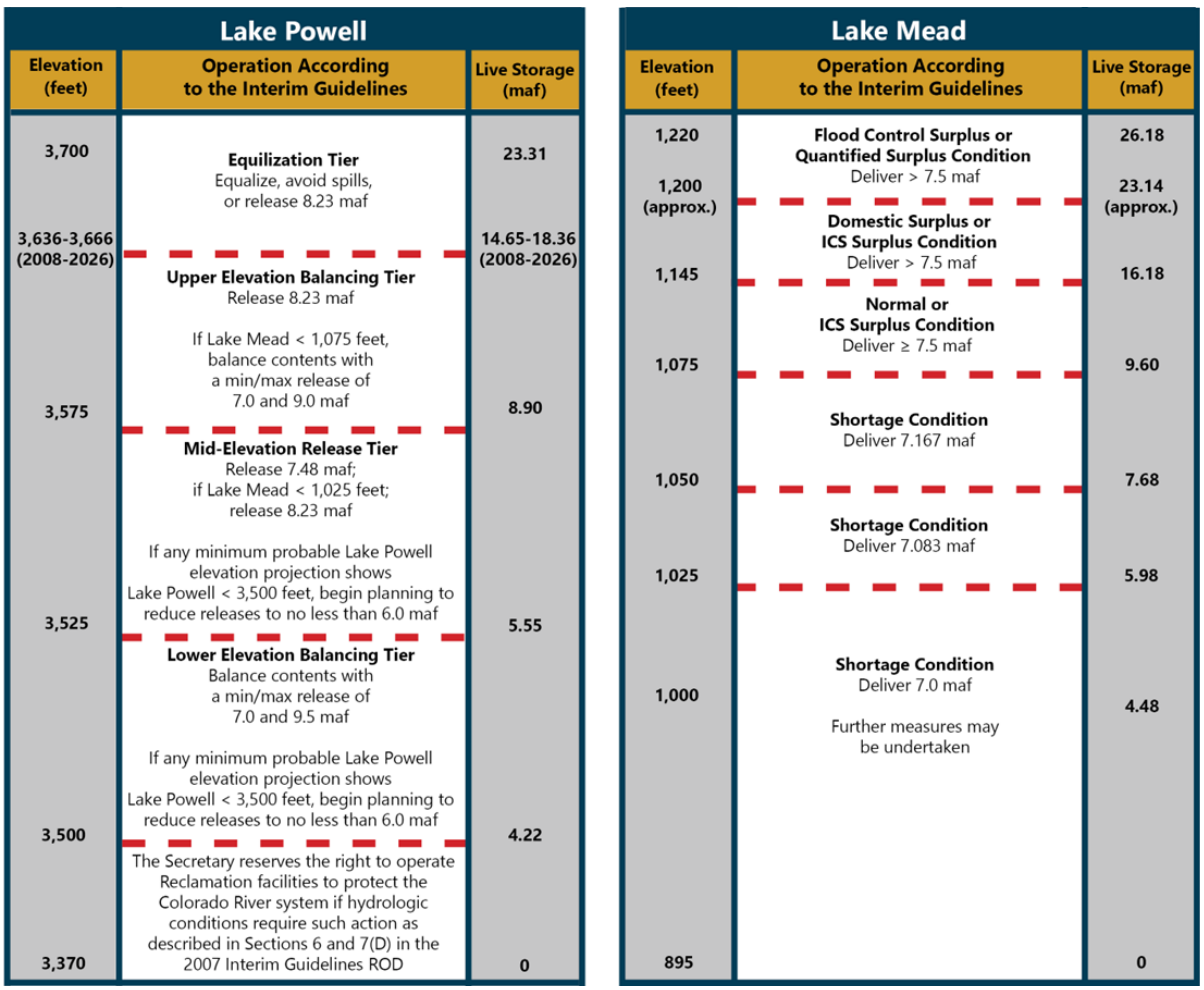

Figure 3 - Operational table for the 2007 Interim Guidelines, as amended by the 2024 SEIS for Near-Term Colorado River Operations ROD (Reclamation, 2024).

2.2.3.2 CRMMS-ESP

CRMMS-ESP is the probabilistic mode within CRMMS, designed for mid-term operations planning and risk assessment over a two to five-year horizon. It provides Basin agencies with information on risk and uncertainty. CRMMS-ESP uses an ensemble of 30 unregulated inflow forecasts for the upper basin, supplied by the CBRFC. These ensemble simulations offer a range of potential future reservoir conditions and operations. Unlike the 24MS, where operations are manually input, CRMMS-ESP simulates reservoir operations using ruleset logic.

2.2.4 Natural Flow Model

The Natural Flow Model (NFM) is used by Reclamation to generate or update the Natural Flow Record (Reclamation, 2020). Natural flow refers to the historical flow data, recorded at gaging stations or dams, adjusted to account for consumptive use, system losses, and reservoir regulation. This adjustment yields the flow that would have been observed in the absence of anthropogenic influences. The natural flow dataset is utilized as the primary hydrologic input in the CRSS model.

2.2.5 CRSS

CRSS is a probabilistic, long-term planning model employed to project basin-wide conditions through 2060 (or longer) on a monthly timestep. CRSS is utilized in risk analyses and policy development to evaluate the impacts on Basin conditions under new or alternative Basin operating agreements. The model incorporates natural flow, defined as the observed flow adjusted for the effects of upstream reservoirs and depletions, as its input hydrology. Similar to CRMMS-ESP, reservoir operations in CRSS are governed by a ruleset that directs decision-making for each hydrologic trace. Hydrologic traces are resampled using the Index Sequential Method (Ourda et al., 1997).

3. Results and Analysis

3.1 Lake Mohave Area and Capacity Curves

The available capacity and surface area of Lake Mohave have been calculated, revealing a total capacity of 2,121,320 af at elevation 655.00 feet (top of dam). Figure 4 illustrates the comparative analysis of area and capacity metrics between the original 1949 study and the 2022 study. Since the 1949 survey, there has been an increase of 77,370 af in capacity, primarily due to enhanced survey accuracy and resolution achieved in 2022, particularly in the deeper canyon sections. The capacity below the main spillway crest is 688,100 af, and the dead storage capacity below the lowest outlet structure is 13,520 af. Table 2 summarizes these survey results in RPVD.

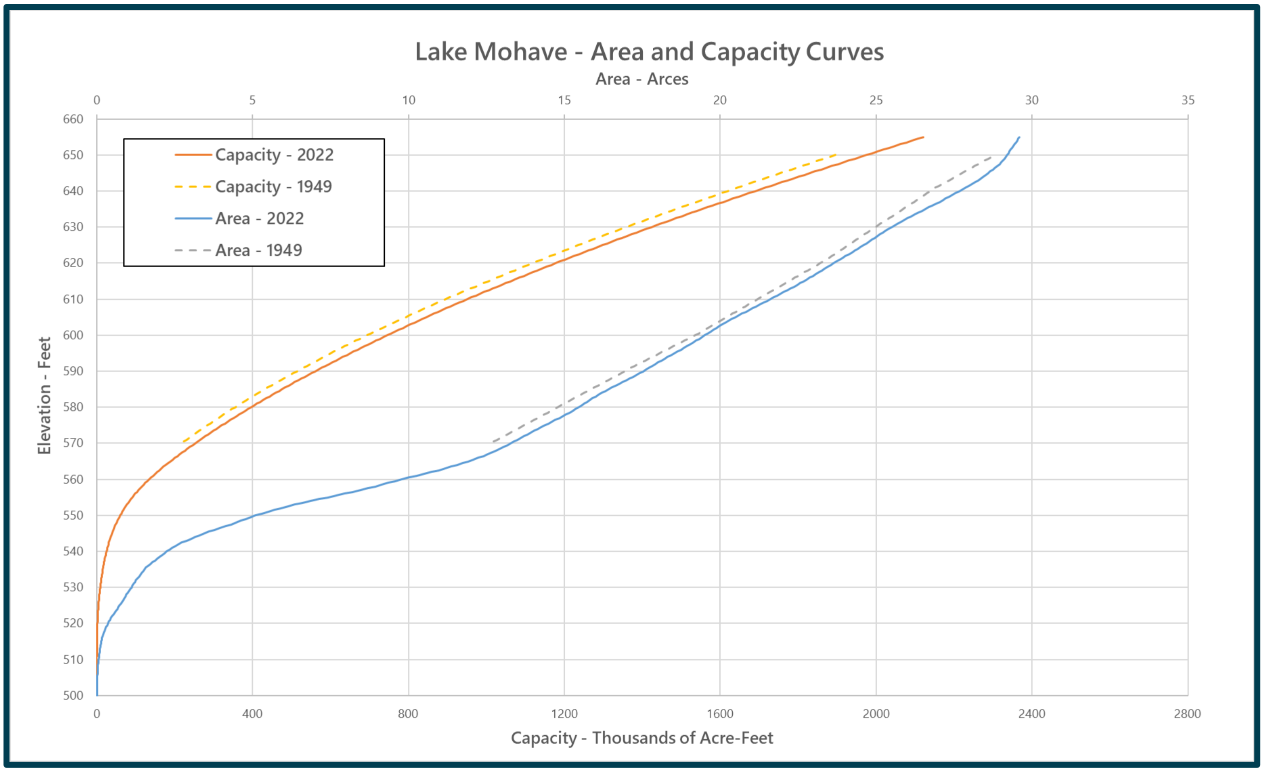

Figure 4 - Graph of Lake Mohave Area and Capacity Curves from 1949 and 2022.

Table 2 - Comparison of Change in Lake Mohave Capacity between 1949 and 2022 studies.

Lake Mohave	Elevation RPVD (feet)	Total Capacity 1949 (af)	Total Capacity 2022 (af)	Δ Capacity (af)
Top of Dam	655.00	NA (Data Not Available)	2,121,320	NA
Top of Spillway Gates	647.00	1,809,800	1,887,170	+77,370
Spillway Crest	597.00	637,000	688,100	+51,100
Bottom of Active Pool	570.00	217,500	252,380	+34,880
Dead Pool	533.39	8,530	13,520	+4,990

The area for Lake Mohave reveals notable changes in surface area compared to the 1949 survey. At the top of the dam (elevation 655.00 feet) the surface area increased by 800 acres to 29,600 acres. Similarly, at the top of the spillway gates (647.00 feet), the area increased by 730 acres to 28,900 acres. The spillway crest (597.00 feet) saw an increase of 390 acres reaching 18,900 acres. Additionally, the 2022 study recorded the bottom of the active pool (570.00 feet) at 13,300 acres and the dead pool (533.30 feet) at 1,400 acres with no comparable data from the 1949 for these elevations. Table 3 summarizes these survey results in RPVD.

Table 3 - Comparison of Change in Lake Mohave Area between 1949 and 2022 studies.

Lake Mohave	Elevation RPVD (feet)	Area 1949 (acre)	Area 2022 (acre)	Δ Area (acre)
Top of Dam	655.00	28,800	29,600	+800
Top of Spillway Gates	647.00	28,170	28,900	+730
Spillway Crest	597.00	18,510	18,900	+390
Bottom of Active Pool	570.00	NA	13,300	NA
Dead Pool	533.30	NA	1,400	NA

3.2 Lake Havasu Area and Capacity Curves

The available capacity and surface area of Lake Havasu have been calculated, revealing a total capacity of 691,920 af at elevation 455.00 feet (top of dam). Figure 5 illustrates the comparative analysis of area and capacity metrics between the original 1957 study and the 2022 study. Lake Havasu has experienced a calculated loss of 29,140 af of capacity at the spillway gates compared to the 1957 survey, which is currently in operational use. This loss is likely due to increased sedimentation and improved survey accuracy and resolution in 2022. Sedimentation from Colorado River tributaries such as the Bill Williams River is suspected, as indicated by the uniform reservoir bottom observed during the 2022 survey. The dead storage capacity below the lowest outlet structure is 20,010 af. Table 4 summarizes these survey results in RPVD.

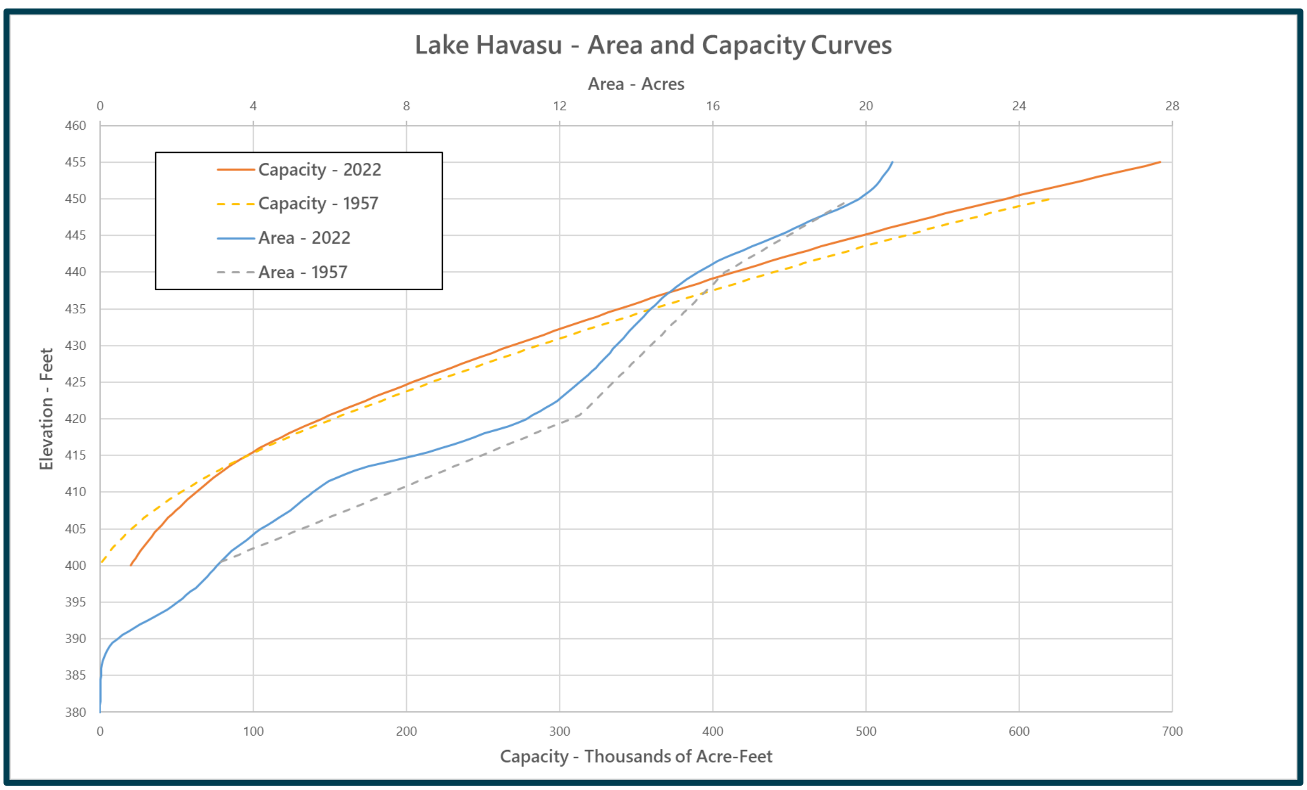

Figure 5 - Graph of Lake Havasu Area and Capacity Curves from 1957 and 2022.

Table 4 - Comparison of Change in Lake Havasu Capacity between 1957 and 2022 studies.

Lake Havasu	Elevation RPVD (feet)	Total Capacity 1957 (af)	Total Capacity 2022 (af)	Δ Capacity (af)
Top of Dam	455.00	NA	691,920	NA
Top of Spillway Gates	450.00	619,400	590,260	-29,140
Bottom of Active Pool	440.00	439,400	413,420	-25,980
Dead Pool	400.00	28,600	20,010	-8,590

The data for Lake Havasu reveal some changes in surface area compared to the 1957 survey. At the top of the dam (elevation 455.00 feet), the surface area in 2022 was recorded at 20,700 acres with no comparable data from earlier surveys. At the top of the spillway gates (450.00 feet), the area increased by 190 acres from 1957, reaching 19,800 acres. The bottom of the active pool (440.00 feet), saw a decrease of 710 acres, resulting in an area of 15,600 acres in 2022. Additionally, dead pool (400.00 feet) was recorded at 3,100 acres in 2022 with no comparable data from earlier survey. Table 5 summarizes these survey results in RPVD.

Table 5 - Comparison of Change in Lake Havasu Area between 1957 and 2022 studies.

Lake Havasu	Elevation RPVD (feet)	Area (acre) 1957	Area 2022 (acre)	Δ Area (acre)
Top of Dam	455.00	NA	20,700	NA
Top of Spillway Gates	450.00	19,610	19,800	+190
Bottom of Active Pool	440.00	16,310	15,600	-710
Dead Pool	400.00	NA	3,100	NA

3.3 Gain/Loss Model

The Gain/Loss model was run using the updated ACAPs spanning January 1981 through December 2023. The revised area and capacity tables specifically influenced the intervening flows in two reaches within the model: the intervening flows from Lake Mead to Lake Mohave and the intervening flows from Lake Mohave to Lake Havasu.

Incorporating the updated ACAPs resulted in a decrease in annual average losses between Lake Mead and Lake Mohave of 4,898 af, as compared to previous survey tables (Table 6). This change is largely offset by the re-computation of historic evaporation on Lake Mohave during the same period, which shows an average annual increase of about 4,910 af. Figure 6 shows the comparison of gain/loss results calculated with the original ACAPs and the new ACAPs data in the Mead to Mohave Reach.

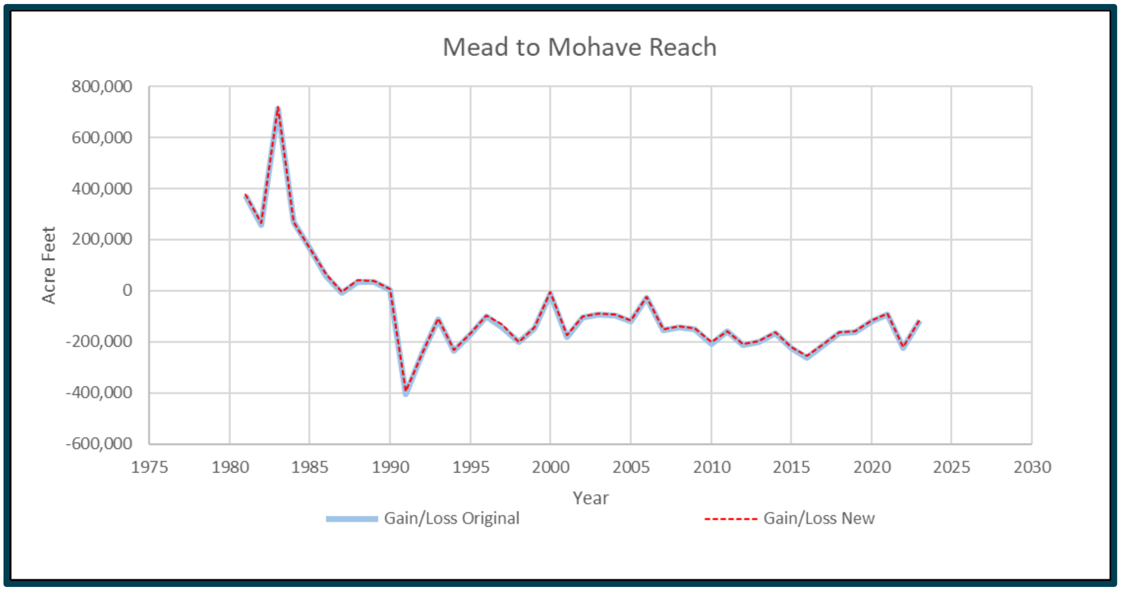

Figure 6 - Comparison of gain/loss results calculated with the original ACAPs and the new ACAPs data in the Mead to Mohave Reach.

Table 6 - Comparison of change in Lake Mohave annual average intervening flow and evaporation between 1981 and 2020. Lake Mead to Lake Mohave reach.

Year	Yearly Average Intervening Flow (af) (original)	Yearly Average Intervening Flow (af) (new)	Difference in Intervening Flow (af)	Yearly Average Evaporation (af) (original)	Yearly Average Evaporation (af) (new)	Difference in Average Yearly Evaporation (af)
1981-2020	-76,014	-71,116	4,898	150,757	155,667	4,910

In the reach between Lake Mohave and Lake Havasu, updating the ACAPs resulted in an increase in average annual intervening flows of 211 af with a corresponding increase in Lake Havasu evaporation of 119 af (Table 7). Figure 7 shows the comparison of gain/loss results calculated with the original ACAPs and the new ACAPs data in the Mohave to Havasu Reach. Such changes in the mass balance underscore the importance of accurately quantifying all components of the mass balance for effective water resources management.

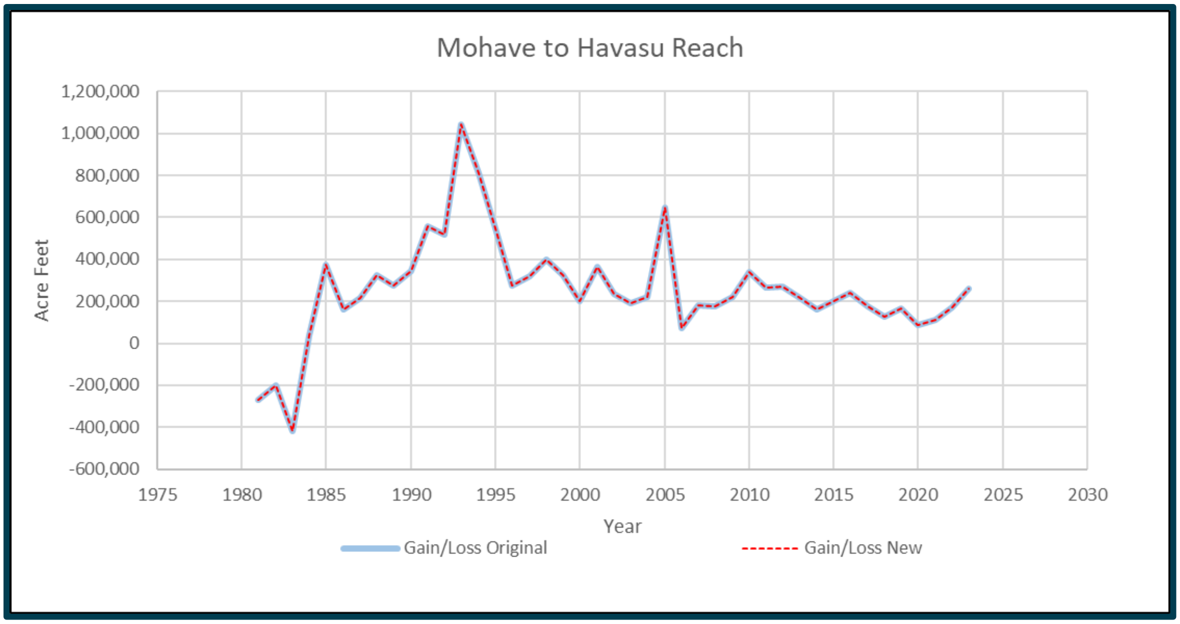

Figure 7 - Comparison of gain/loss results calculated with the original ACAPs and the new ACAPs data in the Mohave to Havasu Reach.

Table 7 - Comparison of change in Lake Havasu annual average intervening flow and evaporation between 1981 and 2020. Lake Mohave to Lake Havasu Reach.

Year	Yearly Average Intervening Flow (af) (original)	Yearly Average Intervening Flow (af) (new)	Difference in Intervening Flow (af)	Yearly Average Evaporation (af) (original)	Yearly Average Evaporation (af) (new)	Difference in Average Yearly Evaporation (af)
1981-2020	260,005	260,216	211	139,432	139,551	119

3.4 24-Month Study

With re-computed intervening flow data, sensitivity analyses were performed for the three most recent April and August 24MS runs. April and August are decision making months according to the 2007 Interim Guidelines and are critical for determining operations at Lake Powell and Lake Mead. Results indicate that impacts of the new ACAPs were minimal and would not have affected operational decisions in the historical model runs.

Unlike Lake Powell and Lake Mead, elevations at Lake Mohave and Lake Havasu follow a yearly, seasonal trend since they are managed using monthly elevation guide curves. There is typically no variability in Mohave and Havasu's projected elevation due to this nature. Each reservoir's guide curve primarily follows the downstream water demand and considers the possibility of high runoff during the late fall and winter seasons.

To understand the impact of using new ACAPs, Lake Mead elevation, evaporation from the main three lower basin reservoirs, and outflow from Lake Mead and Lake Mohave were evaluated in the sensitivity analysis. Since the model runs did not start or end within a full CY or WY, parameters were evaluated based on time intervals covering April through December or August through December of the first year of the model run's simulation period (year 1), depending on the starting month. Elevation values were compared at EOCY, since the 2007 Interim Guidelines bases annual operations on projected EOCY elevations.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
April 24MS	Historical						Projected (Year 1)					Decision Point	Projected		
August 24MS	Historical										Projected				Decision Point

Figure 8 - 24-Month Study decision making horizons.

The sensitivity analysis indicates a relatively small difference to each of the reservoir parameters evaluated. Results indicate that the outflows from Hoover dam bore differences ranging from -1,103 af to 723 af for April studies, and -485 af to 854 af for August studies, as shown in Table 8 and Table 9 below. This range shows a percent difference is negligible given the uncertainty in projections, generally around 0.02% or lower. Lake Mohave outflow differences were even lower, at -53 af to 328 af for April studies and -61 af to 306 af for August studies, which again, are negligible with respect to the impact on operations.

Table 8 - April 24MS Year 1 Outflows Sensitivity Analysis.

Year of Model Run	Reservoir	Original ACAPs Outflow (af)	New ACAPs Outflow (af)	Difference
2022	Lake Mead	6,756,777	6,756,910	133
	Lake Mohave	6,600,672	6,600,651	-21
2023	Lake Mead	6,570,747	6,569,644	-1,103
	Lake Mohave	6,452,953	6,452,900	-53
2024	Lake Mead	6,786,660	6,787,383	723
	Lake Mohave	6,632,777	6,633,105	328

The April Study outflows in Table 8 were calculated as a sum of April through December projections in year 1. Similarly, the August Study outflows in Table 9 were calculated as a sum of August through December projections in year 1.

Table 9 - August 24MS Year 1 Outflows Sensitivity Analysis.

Year of Model Run	Reservoir	Original ACAPs Outflow (af)	New ACAPs Outflow (af)	Difference
2022	Lake Mead	2,881,197	2,880,712	-485
	Lake Mohave	2,874,445	2,874,543	98
2023	Lake Mead	2,777,670	2,778,524	854
	Lake Mohave	2,736,885	2,736,824	-61
2024	Lake Mead	2,892,505	2,892,689	184
	Lake Mohave	2,879,213	2,879,519	306

With respect to evaporation, Lake Mohave results showed the largest differences between the sensitivity and original runs as shown in Table 10 and Table 11. Lake Mohave's evaporation in year 1 of the model run increased by 2,231 to 4,084 af through the EOCY, depending on the start month. Differences observed in evaporation for Havasu range from -92 to 162 af and for Mead were -1 to 42 af. The low changes at Lake Mead can be explained by a combination of change of target storage at Lake Mohave and Lake Havasu and changes to Lake Mead's outflows to sustain those target storages.

Table 10 - April 24MS Total Year 1 Evaporation Sensitivity Analysis

Year of Model Run	Reservoir	Original ACAPs Total Evaporation (af)	New ACAPs EOCY Total Evaporation (af)	Difference of Evaporation (af)
2022	Lake Mead	380,630	380,660	30
	Lake Mohave	124,286	128,370	4,084
	Lake Havasu	116,473	116,580	107
2023	Lake Mead	403,008	403,050	42
	Lake Mohave	124,352	128,420	4,068
	Lake Havasu	116,458	116,620	162
2024	Lake Mead	409,824	409,830	6
	Lake Mohave	124,267	128,350	4,083
	Lake Havasu	116,382	116,500	118

Table 11 - August 24MS Total Year 1 Evaporation Sensitivity Analysis.

Year of Model Run	Reservoir	Original ACAPs Total Evaporation (af)	New ACAPs EOCY Total Evaporation (af)	Difference of Evaporation (af)
2022	Lake Mead	209,947	209,950	3
	Lake Mohave	71,399	73,630	2,231
	Lake Havasu	59,492	59,400	-92
2023	Lake Mead	234,321	234,320	-1
	Lake Mohave	72,063	74,480	2,417
	Lake Havasu	59,421	59,350	-71
2024	Lake Mead	233,402	233,410	8
	Lake Mohave	71,327	73,560	2,233
	Lake Havasu	59,471	59,410	-61

Table 12 below shows the net change in elevation projections, given the small differences in outflows and evaporation at Lake Mead. The changes to elevation projections at the reservoir are nearly negligible due to the small changes in mass balance. The Lake Mead elevations using the new ACAPs tables showed differences ranging from -0.03 feet to -0.01 feet. That the differences did not even exceed a tenth of a foot indicates that the new ACAPs tables would have no impact on Lake Mead operations.

Table 12 - April 24MS EOWY elevation projections for the original area capacity tables and sensitivity runs with new area capacity tables for Lake Mead.

Year of Model Run	Original ACAPs EOWY Elevation Projection (feet)	New ACAPs EOWY Elevation Projection (feet)	Difference	Change in Operations?
2022	1,045.37	1,045.34	-0.03	No
2023	1,067.17	1,067.16	-0.01	No
2024	1,060.29	1,060.26	-0.03	No

The April projections of EOWY elevations are important because under certain Powell operating tiers, these projections can result in changes to Powell's annual release. In 2022, Powell operated in the Mid-Elevation release tier; however, due to extremely dry hydrology and the risk of Powell declining to minimum power pool, Powell's annual release was lowered to 7.0 maf – this operation would have taken place regardless of Lake Mead's elevation. The 2023 sensitivity analysis did indicate a slight change to Powell operations. In 2023, Powell operated in the Lower Elevation Balancing Tier, with an initial annual release of 7.0 maf. Due to wet conditions in the upper basin, Powell shifted to Balancing releases in April 2023. With slight changes to Lake Mead's projected elevation, the balancing release from Powell did not change significantly (less than 0.01 thousand acre feet [kaf]). In 2024, Powell operated again in the Mid-Elevation release tier, with a set annual release of 7.48 maf, not subject to balancing or other adjustments based on Lake Mead's elevation.

The August 24MS runs could impact Lake Mead's operating condition for the following year. The sensitivity analysis showed that there would be no changes to Lake Mead's operating condition in any of the three model runs. Table 13 indicates that neither the operating condition as set forth by the 2007 Interim Guidelines, nor the additional water savings outlined in the Lower Basin Drought Contingency Plan would have differed.

Table 13 - August 24MS EOCY elevation projections from the original and sensitivity for Lake Mead.

Year of Model Run	Original ACAPs EOCY Elevation Projection (feet)	New ACAPs EOCY Elevation Projection (feet)	Difference	Change in Operations?
2022	1,040.78	1,040.78	0.003	No
2023	1,065.27	1,065.27	0.001	No
2024	1,062.32	1,062.32	0.000	No

3.5 CRMMS-ESP

The January 2024 CRMMS-ESP model was re-run incorporating the new ACAPs tables, including target storage at Lake Mohave and Lake Havasu, and updated gain/loss data used in the index sequential process. For the purposes of the sensitivity analysis, simulated years beyond 2026 assume a continuation of the 2007 Interim Guidelines, the 2019 Colorado River Drought Contingency Plans, and Minute 323 including the Binational Water Scarcity Contingency Plan. Reclamation initiated the process to develop operations for post-2026 in June 2023; however, this does not negate the findings of the sensitivity analysis using the new ACAPs versus the old ACAPs, as operations were modeled identically in both model runs.

Figure 9 below illustrates the differences in operational tier projections using the new ACAPs tables. In 2026, one trace shifted from a level 2 shortage to a level 1 shortage. In both 2027 and 2028, one trace shifted from a level 1 shortage condition to a normal condition. These results indicate that the small changes in operations accumulate over time and start to become more visible beyond 2-years. With only one trace changing in each of years 3-5 of the CRMMS-ESP model run, implementing the new ACAPS has a very small impact to even the 5-year operational projections.

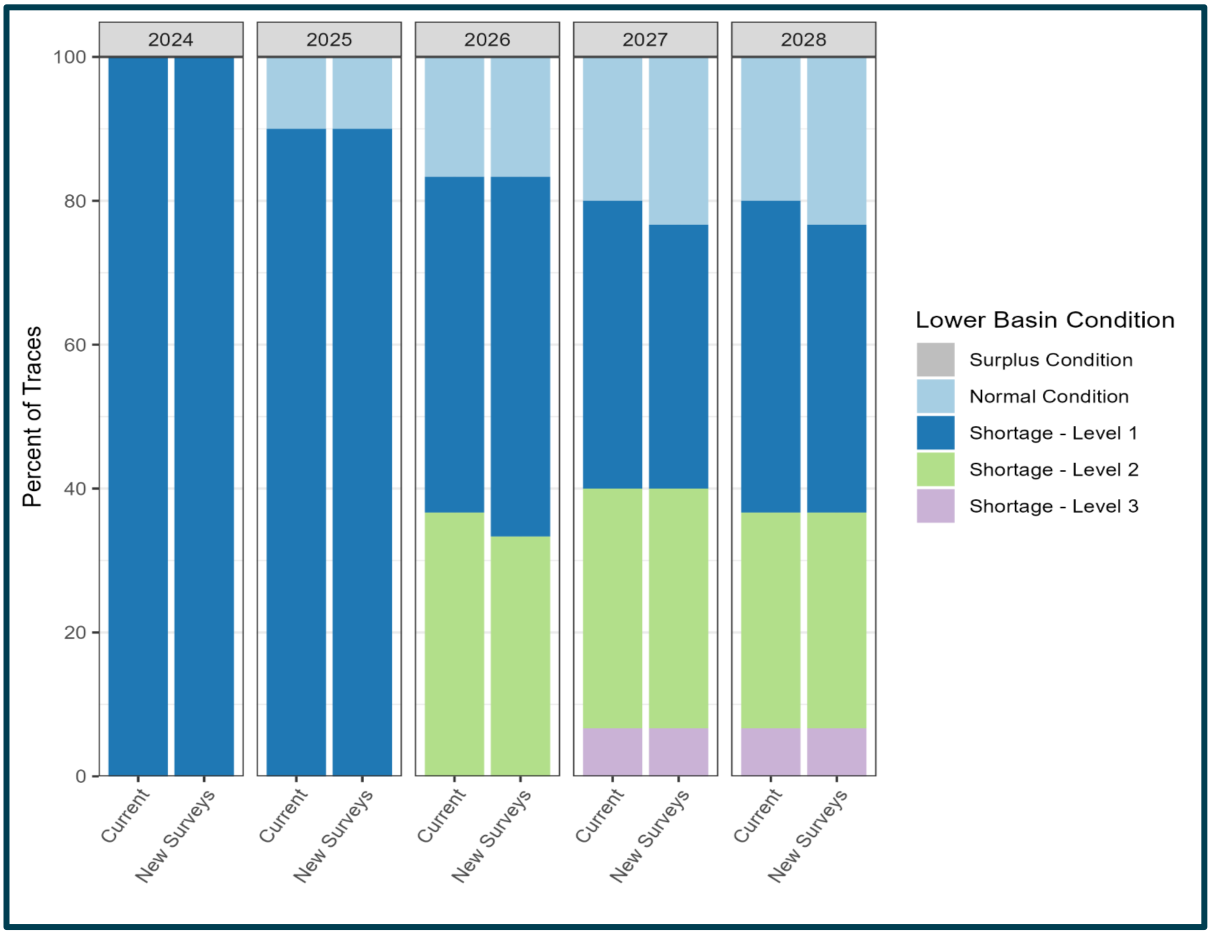

Figure 9 - Comparison of the likelihood of operating conditions from the January 2024 CRMMS-ESP scenarios.

The effects of the new ACAPs tables can be seen in Lake Mead and Lake Powell elevation projections (Figure 10 and Figure 11). These figures each show a cloud plot along with separate lines detailing the 10th, 50th, and 90th percentiles for end of month elevation projections. The results show that running CRMMS ESP with the new ACAPs results in a slightly wider range of Lake Mead pool elevation projections, particularly in the later years of the run. The 10th and 90th percentiles are a little lower with the new ACAPs than with the old ACAPs, however the median elevation projection is very similar for both runs. The results for Lake Powell showed an average difference in pool elevation of 0.15 feet over the entire length of the run. There were no changes to projected operational tiers for Lake Powell. The small differences in elevation were due to differences in outflow during balancing/equalization operations, on average 0.49 kaf over the length of the run.

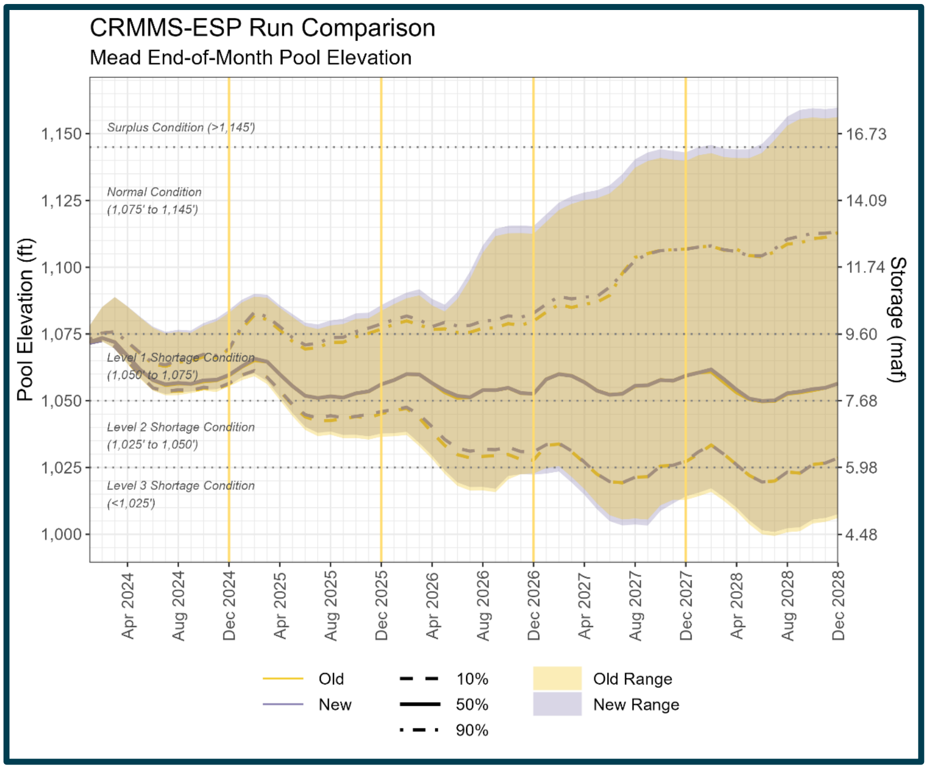

Figure 10 - Comparison of the projected 10th, 50th, and 90th percentile of End-of-Month Lake Mead elevations from the January 2024 CRMMS-ESP scenarios.

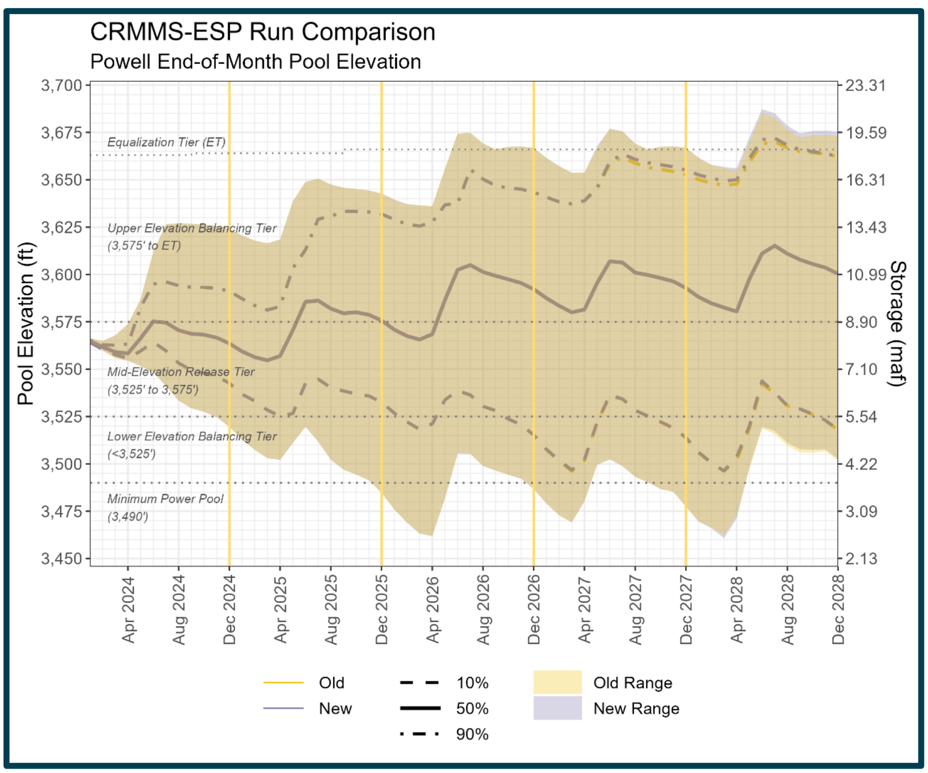

Figure 11 - Comparison of the projected 10th, 50th, and 90th percentile of End-of-Month Lake Powell elevations from the January 2024 CRMMS-ESP scenarios.

3.6 Natural Flow Model

A sensitivity analysis was also performed on Reclamation's NFM. A summary of the changes in the annual naturalized intervening flows due to incorporation of the new ACAPs tables is below in Figure 12 for Mead to Mohave Reach and Figure 13 for the Mohave to Havasu Reach.

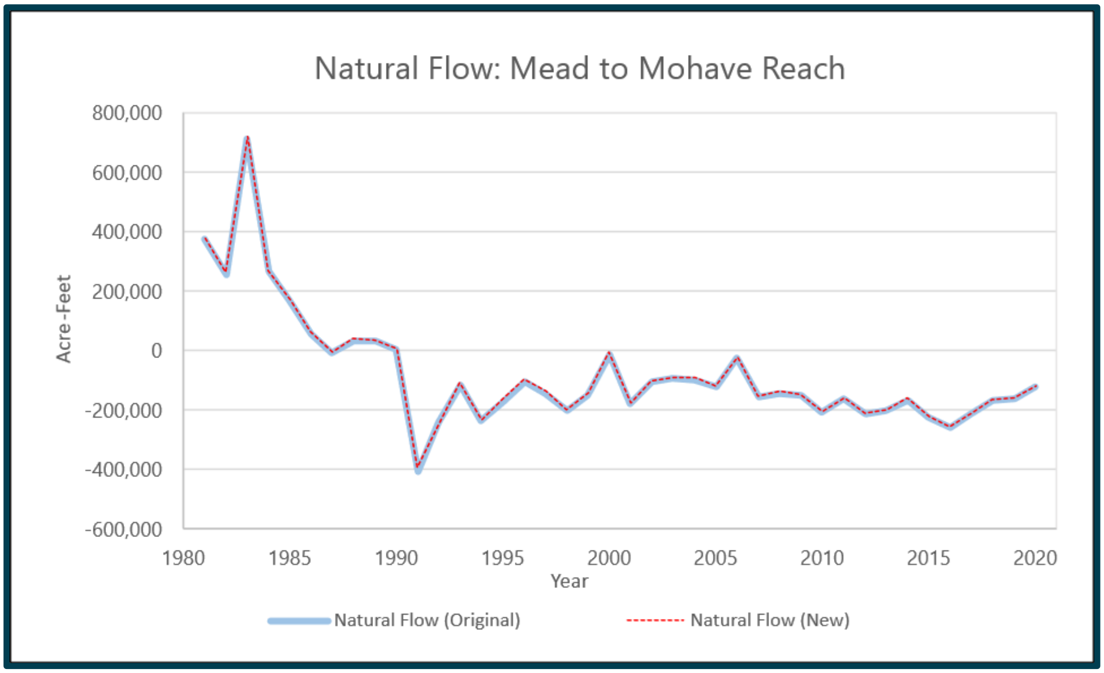

Figure 12 - Comparison of intervening natural flow from original ACAPs data and new ACAPs data for Mead to Mohave Reach.

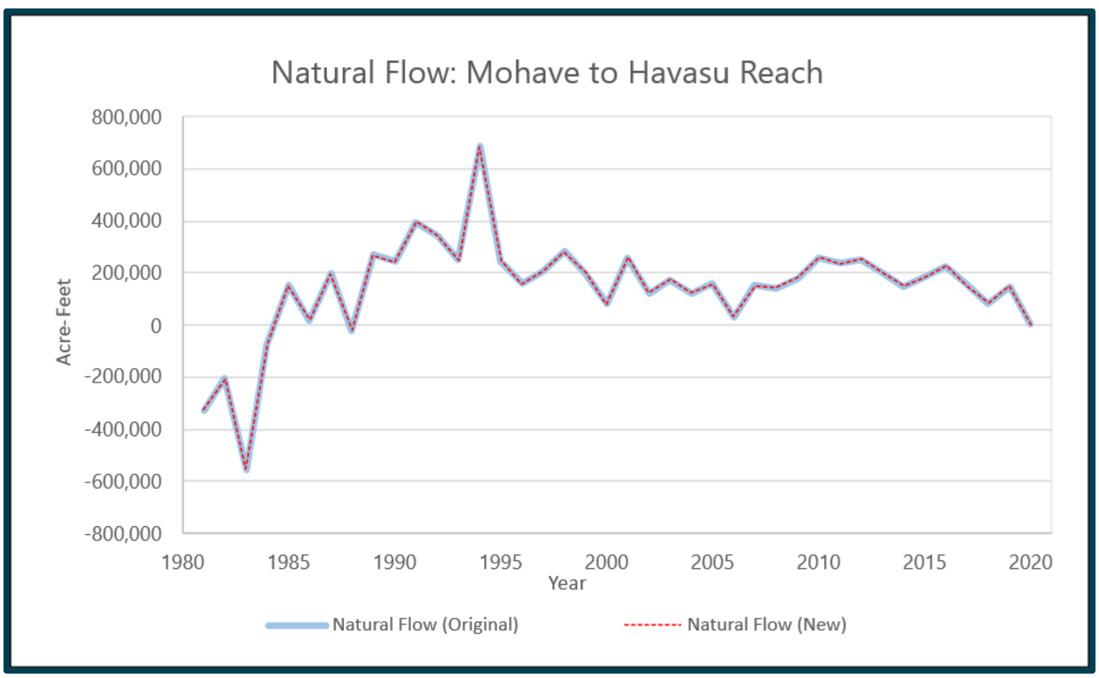

Figure 13 - Comparison of intervening natural flow from original ACAPs data and new ACAPs data for Mohave to Havasu Reach.

Table 14 shows the difference in intervening flows after the integration of the updated ACAPs into the model. Intervening natural flows at Lake Mohave exhibited an average annual increase of about 4,900 af (0.46% change), a similar change seen in the Gain/Loss Model for the same reach. Intervening natural flows at Lake Havasu showed minimal change, with an average annual increase of 116 af (0.05% change).

Table 14 - Comparison of change in Natural Flow

Reach	Year	Yearly Average Natural Flow (af) (original)	Yearly Average Natural Flow (af) (new)	Difference in Natural Flow (af)	Percent difference (%)
Mead to Mohave	1981-2020	-75,997	-71,095	4,906	1.14
Mohave to Havasu	1981-2020	145,002	145,118	116	0.06

3.7 CRSS

The sensitivity analysis in this technical memorandum uses one scenario developed from the observed natural flow record, computed with Reclamation's NFM, as the future hydrology. The "stress test" hydrologic record resamples the full record from 1988 to 2020 using the Index Sequential Method (Ouarda et al. 1997) resulting in 33 hydrologic inflow traces. Similar to CRMMS-ESP, operations in CRSS are simulated with ruleset logic. For this technical memorandum, the August 2023 official CRSS model run was used to project system conditions from 2024 to 2056. The analysis uses the 2016 Upper Colorado River Commission demand schedule for the Upper Division States' future water demands. Future water demands for the Lower Division States, during normal conditions, are set according to the schedules provided for the 2007 Final Environmental Impact Statement for the 2007 Guidelines with updates to Nevada's demands dated May 2019.

Although the CRMMS-ESP section indicates that the changes in projected operations are minimal over a five-year period, small annual changes can compound and may affect reservoir operations when looking at long term planning. To understand the effects beyond five years, CRSS was used to simulate system conditions from 2024 to 2056.

A comparison of the projected 10th, 50th, and 90th percentile of EOCY elevations at Lake Mead and Lake Powell are shown in Figure 14 and Figure 15, respectively. At the 50th percentile (median) the average difference in Lake Mead projected elevations between 2024 and 2039 is 0.40 feet, with an average difference between 2040 and 2056 of 1.14 feet. From 2024 to around 2034, Lake Mead shows higher elevations—particularly in the upper percentile traces—due to wetter hydrologic conditions early in the simulation, which support increased storage at Lake Powell and allow for equalization releases to Lake Mead. After 2034, a sharp decline in elevation occurs, especially in the higher percentiles, as drier conditions reduce reservoir storage and the equalization line grows to higher elevations, equalization ceases. The decline then stabilizes at lower levels, as continued dry conditions and operational constraints limit the system's ability to recover.

The average difference in the Lake Powell 50th percentile of projected elevations between 2024 and 2039 is -0.40 feet, with an average difference between 2040 and 2056 of 0.96 feet.

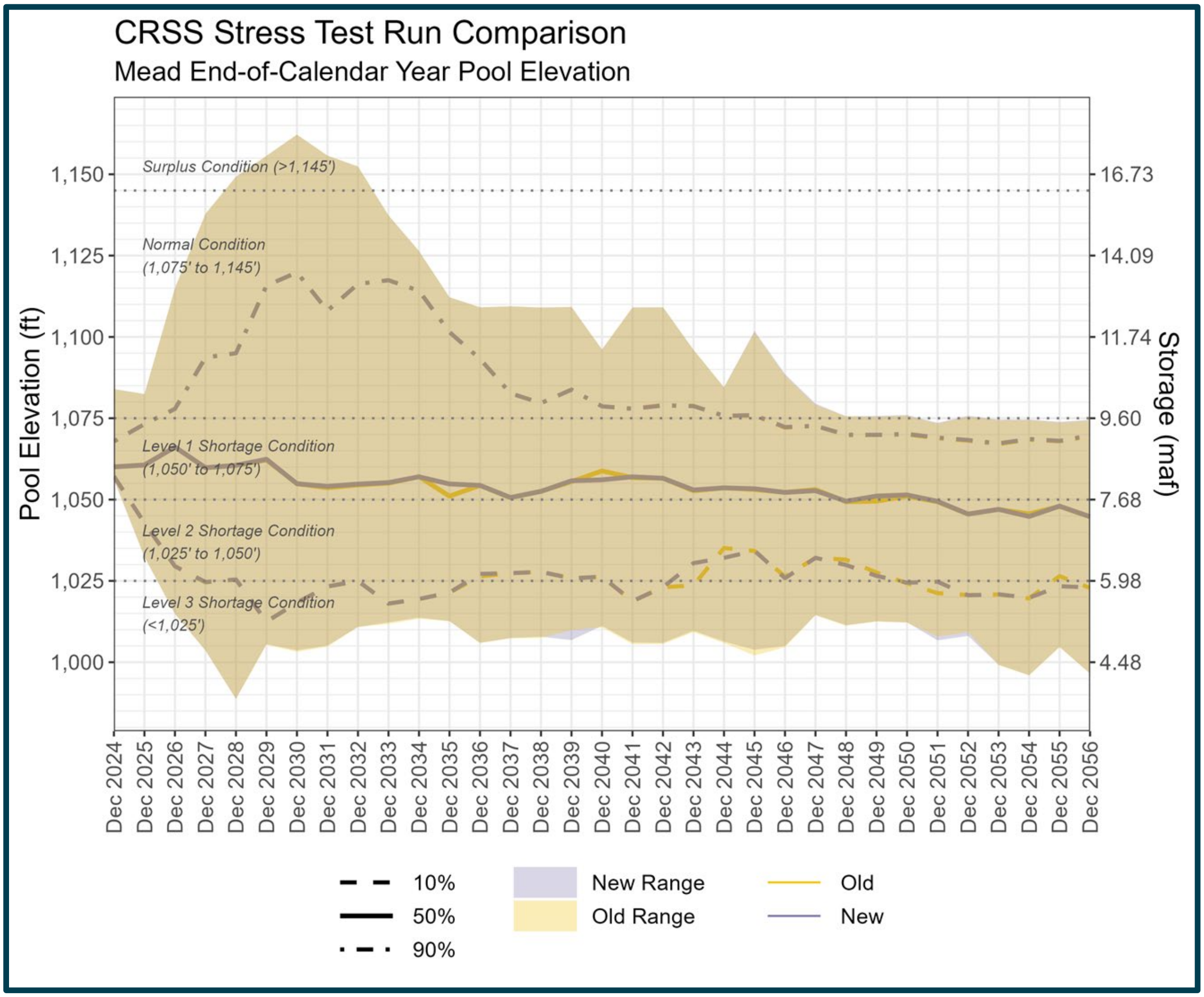

Figure 14 - Comparison of the projected 10th, 50th, and 90th percentile of EOCY Lake Mead elevations from the August 2023 CRSS run from 2024 through 2056 with the stress test natural flow record hydrology (1988-2020).

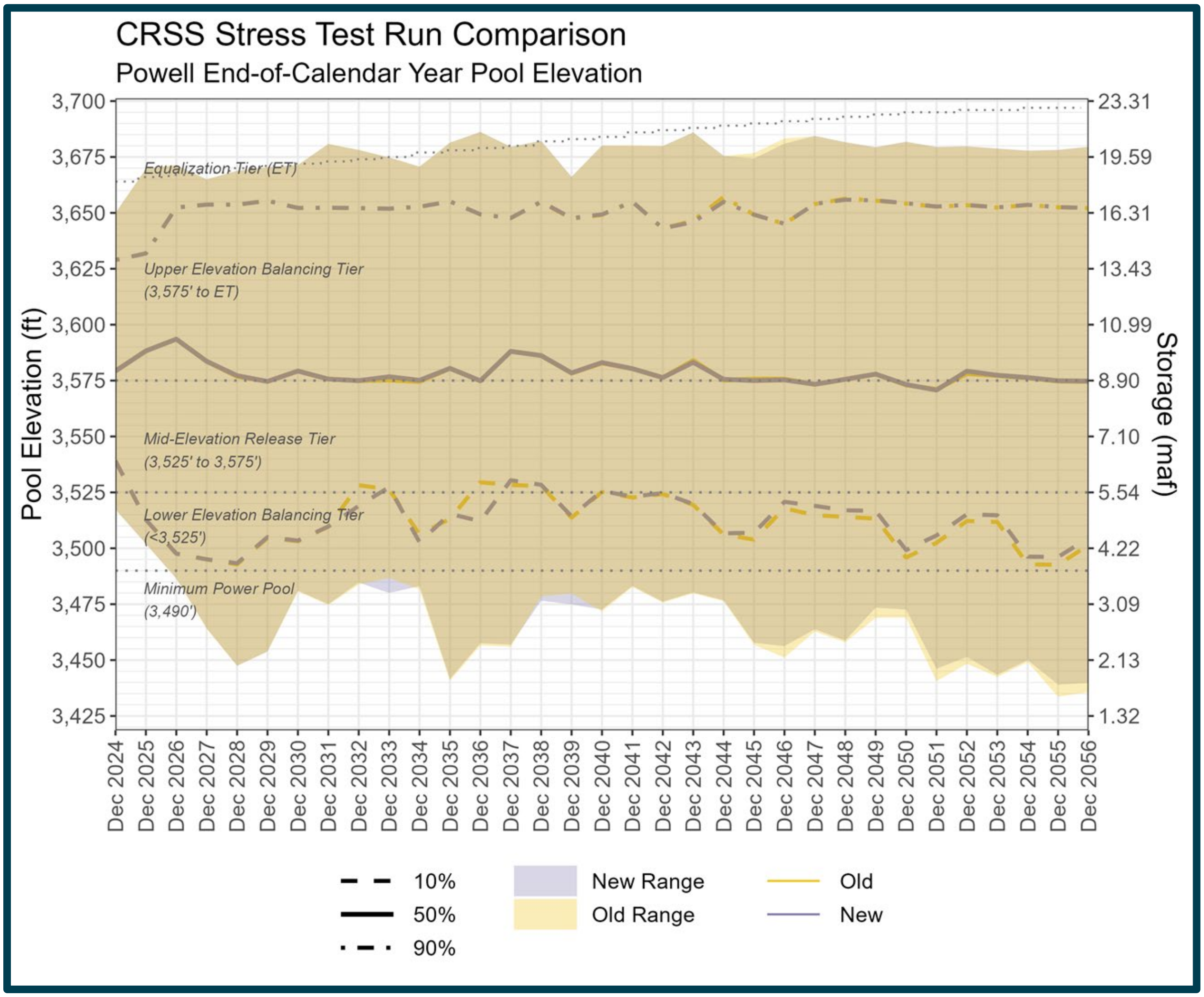

Figure 15 - Comparison of the projected 10th, 50th, and 90th percentile of EOCY Lake Powell elevations from the August 2023 CRSS run from 2024 through 2056 with the stress test natural flow record hydrology (1988-2020).

Even with small changes in elevation it is possible that the operating tier at either Lake Powell or Lake Mead can change due the compounding effects of operations over time. Figure 16 is an example of changes in operating conditions using the percent of traces that project the lower basin to be in shortage conditions, consistent with the 2007 Interim Guidelines shortage criteria. Consistent with the changes in Lake Mead elevations, projections with the new ACAPs show small shifts in the percentage of lower basin shortages, although the year-to-year increases and decreases tend to cancel each other out to an average of just 1% higher for 2040-2056 compared to the old ACAPs.

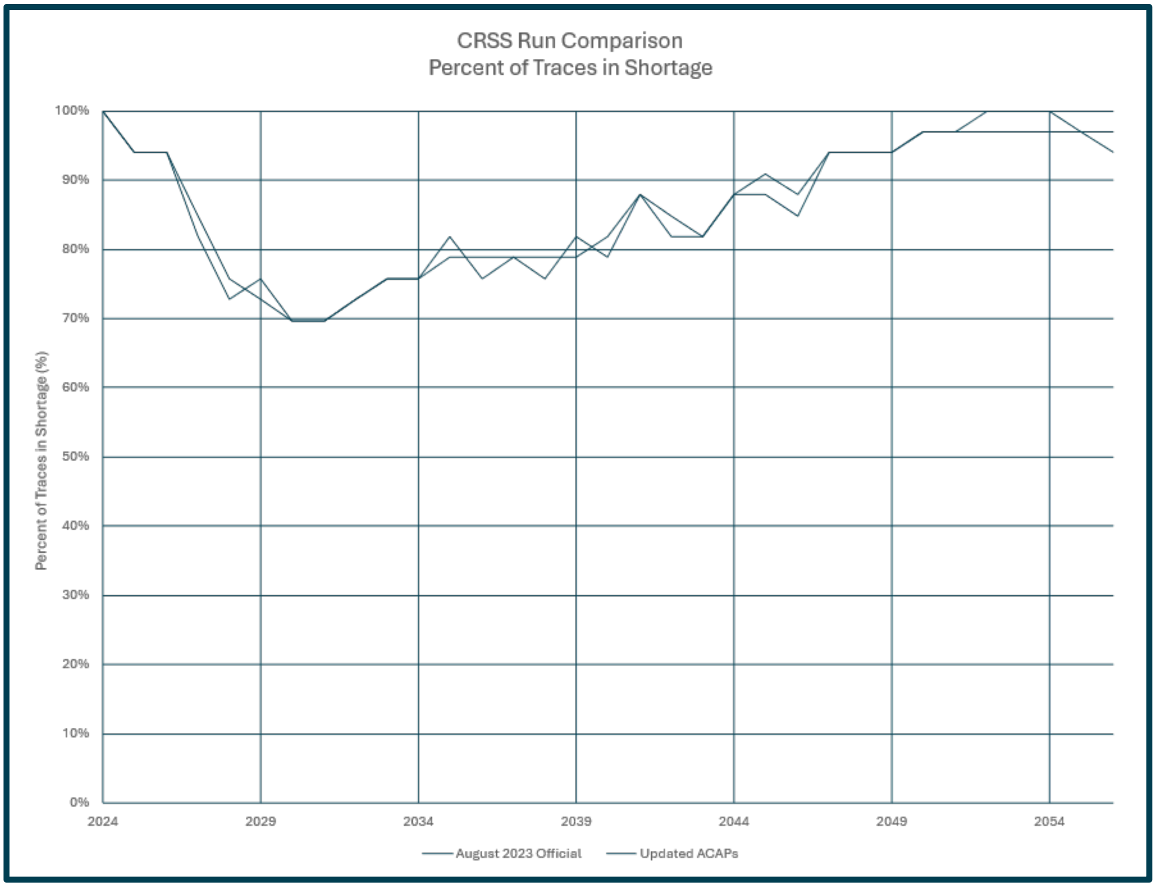

Figure 16 - Comparison of the percent of traces in lower basin shortage from the August 2023 CRSS run from 2024 through 2056 with the stress test natural flow record hydrology (1988-2020).

4. Conclusion

The sensitivity analyses of the new ACAPs show minimal impacts to lower basin reservoir projections in both the mid-term and long-term Colorado River Basin models. The sensitivity analyses indicated that Lake Mead operating conditions would not be significantly impacted by implementation of the new tables on an operational basis.

The results of the 2021 and 2022 surveys capture a more accurate representation of reservoir capacity and surface area, as well as the various elements of the mass balance evaluated in the mid-term and long-term analyses. The results of this technical report support the implementation of the new ACAPs for Lake Mohave and Lake Havasu. The outcomes of this study provide water managers and interested parties with the knowledge that the best available information is being used appropriately to track current reservoir conditions in the Basin, and project future reservoir conditions at Lake Mead.

Conducting regular reservoir surveys can ensure that critical data remains current and reflective of ongoing sedimentation conditions and technological advancements, enabling continuous improvement in the accuracy and reliability of hydrologic and operational data for record-keeping and model projections.

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