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Meeting Logistics Summary

- Roll Call
 - Members will unmute and acknowledge their attendance when their name is called.
- Modeling and Analysis Workgroup Members
 - If in the room, please raise your hand.
 - If online, use the Teams "raise hand" feature to request to speak or ask questions.
 - Wait to be recognized before speaking to ensure clear communication and remain muted when not speaking.

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MAWG #8 – Meeting Agenda

- Welcome and Introductions
- MAWG Overview and Purpose
- Colorado River Simulation System version 6 (CRSS v6)
- Post-2026 Lower Basin Alternative
- MAWG Next Steps
- MAWG #9 Late March/Early April 2024

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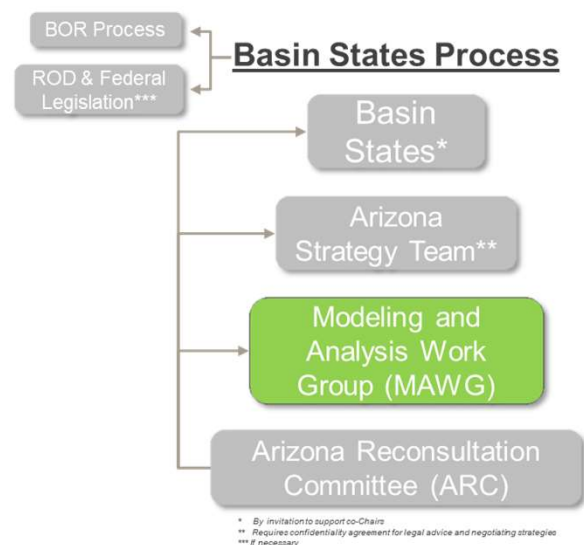
MAWG Overview

Modeling and Analysis Workgroup established by the Arizona Reconsultation Committee (ARC)

Co-chaired by ADWR and CAWCD

Purpose:

Support ARC decision-making by providing fact-based analysis of risks, vulnerabilities, and impact to Arizona's overall Colorado River supply including On-River and CAP users.



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MAWG #8 Purpose and Goals

- Lower Basin States Alternative was submitted to Bureau of Reclamation on March 6, 2024
- Arizona Reconsultation Committee (ARC) meeting held on March 6, 2024
- MAWG #8 is convened to further discuss technical details of the Lower Basin Alternative
- Develop baseline understanding of analysis tools, visualizations, and metrics

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Colorado River Simulation System (CRSS)

- Primary tool distributed by Bureau of Reclamation for analyzing future river and reservoir conditions in a long-term planning context
- Implemented in RiverWare
- Reclamation did extensive work in 2021 and 2022 to improve certain model functionality
- CRSS version 6.0 was released in March 2023
 - Includes additional hydrologies and changes to how Upper Basin demands are simulated

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Colorado River Simulation System (CRSS)

Features represented by Objects, Links, Subbasins, Slots, etc.

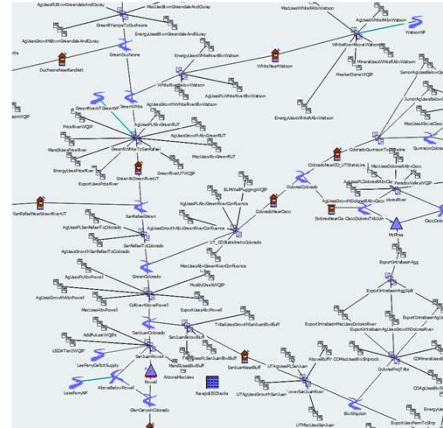
- Rivers
 - UB: Colorado, Green, San Juan, and their major tributaries
 - LB: Mainstem Colorado and some tributaries
- 15 Major Reservoirs
- 500+ Water Users

Inputs

- Hydrology (supply)
 - Upper Basin: 21 natural flow points
 - Lower Basin: 8 inflow points for gaged & intervening flows
- Demands
- Initial Conditions
- Model operating rules (policy)

Outputs

- Monthly timeseries and statistics
- Reservoir levels, Water use, River flow, Energy generation



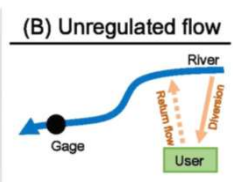
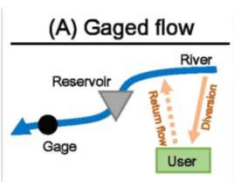
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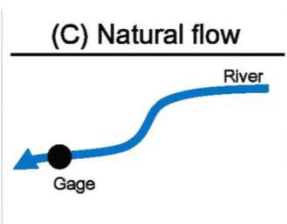
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CRSS Hydrologies: Flow Types



Gaged Flow: the flow measured by a stream gage with actual reservoir operations and diversions

Unregulated flow: the flow that would have been observed at a stream gage if there were no upstream reservoirs present (includes evaporation and bank storage) – used for 24-month study and CRMMS (BOR 2- to 5-year modeling tool)



Natural flow: the flow that would have been observed at a stream gage if there were no upstream reservoirs or diversions present

Natural flow is required for hydrology input to allow for CRSS to model potential changes to reservoir operations under varying projections of both supply and demand

Descriptions of gaged, unregulated, and natural flow adapted from Wheeler et al. (2019)



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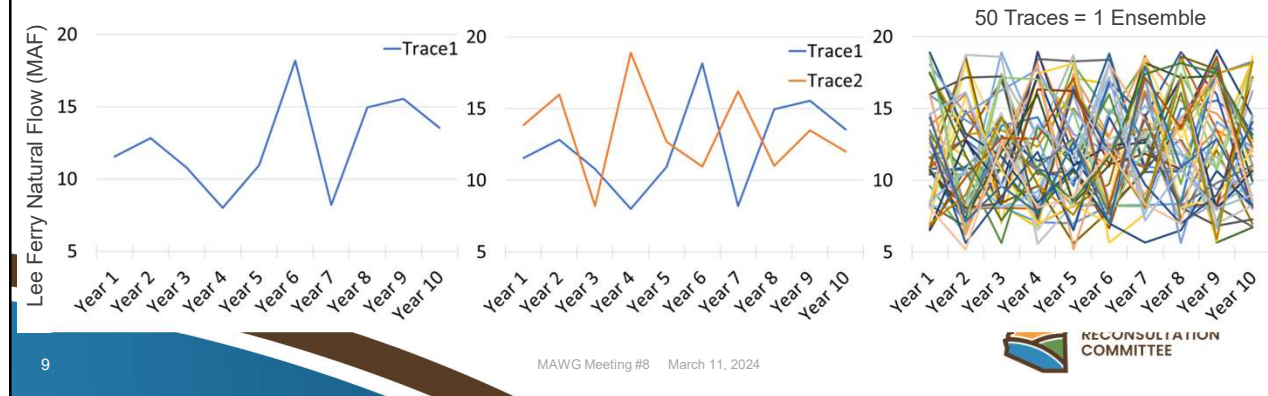
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CRSS Hydrologies: Trace / Ensemble

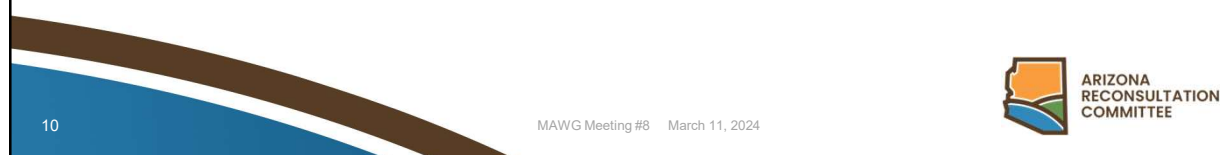
- CRSS projections are most sensitive to future hydrology, and future inflows are the largest source of uncertainty
- Hydrology scenarios are developed that consists of many **traces**
 - A trace is a single timeseries of future natural flow
 - Traces are combined to create an **ensemble**



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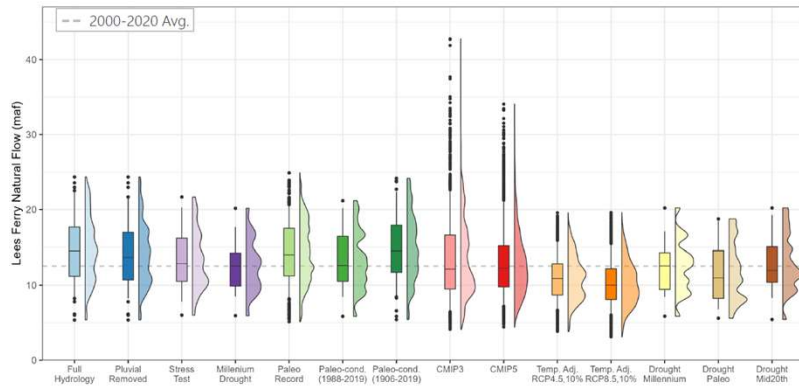
CRSS Hydrologies: Considered Ensembles

- Reclamation evaluated a wide range of hydrology ensembles based on a combination of characteristics including data sources, previous applications, ensemble statistics and patterns, using a machine learning clustering algorithm
- For analysis of Post-2026 Alternatives, Reclamation ultimately selected **five ensembles, with a total of 400 traces**
- The selected hydrologies cover a wide range of minimum and maximum flow sequences that extend beyond the historical records, especially for the minimum flows



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CRSS Hydrologies: Considered Ensembles



Observed Historical (Index Sequential Method to resample natural flows)

- Full (1906 to 2020)
- Pluvial removed (1931 to 2020)
- Stress test (1988 to 2020)
- Millennium Drought (2000 to 2020)

Paleohydrology

- Paleo (Resampling of 1416 to 2015 paleo record)
- Paleo-conditioned (blend of paleo record and natural flow record)

Climate Model-Informed

- CMIP3
- CMIP5

Recently Developed Ensembles

- Temperature Adjusted Ensembles
- Utah State University Drought Ensembles



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CRSS Hydrologies: Selected Ensembles and Traces

- **Stress Test – 33 Traces**
 - Index sequential method (ISM) using 1988-2020 historical natural flows
- **CMIP5 LOCA KNN – 64 Traces**
 - Coupled Model Intercomparison Project (CMIP) 5, downscaled using Localized Constructed Analogs (LOCA), extrapolating streamflow using k-nearest neighbors (KNN)
- **Post-pluvial NPC Temperature Adjusted – 100 Traces**
 - Nonparametric Paleo-conditioned (NPC) sampling of the pluvial removed record (1931-2020), adjusted to reflect sensitivity of observed warming trend (Milly and Dunne (2020): -9.3%/°C of warming) and used Meko (2017) to define wet/dry sequences from paleo record
- **Paleo Drought Subsample Resample – 50 Traces (of 100)**
 - Utah State ensemble that resampled 1576-1600 drought
- **CMIP3 BCSD NPC Subsample – 153 Traces (of 5,600)**
 - CMIP3 downscaled using Bias-Corrected and Spatial Disaggregation method, and NPC sampling using Meko (2017) to define wet/dry sequences from paleo record



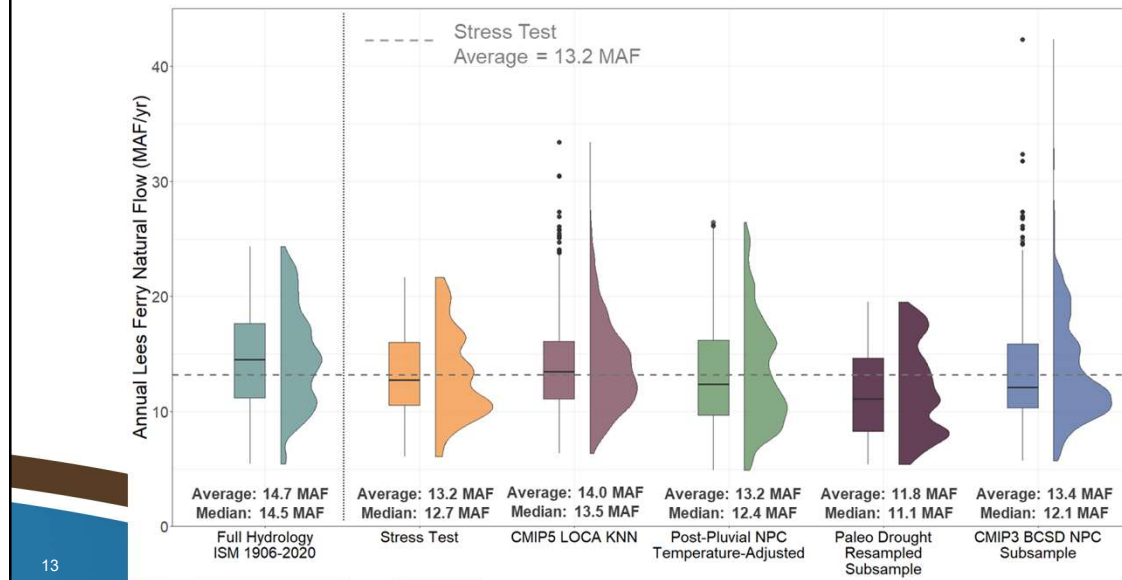
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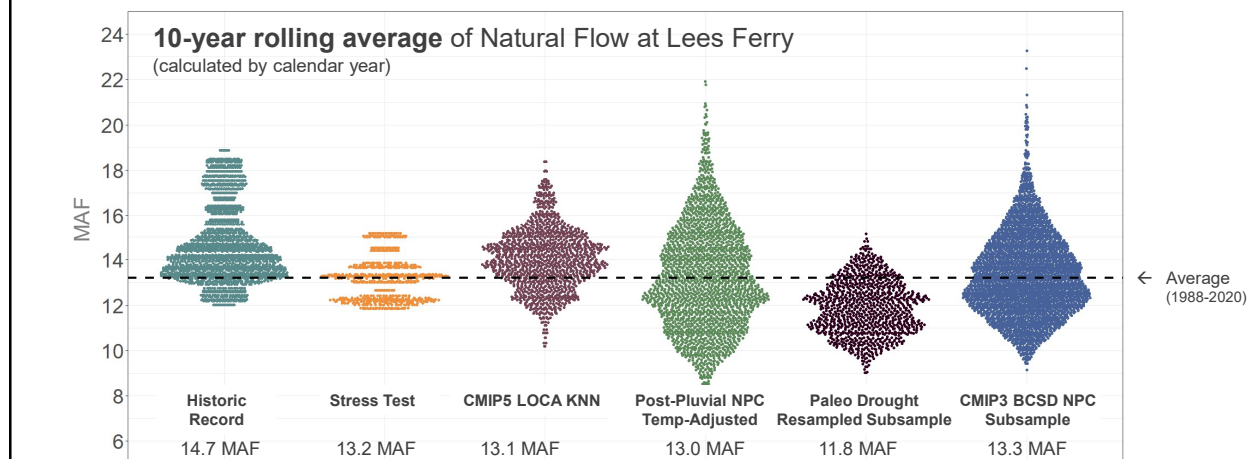
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CRSS Hydrologies: Selected Ensembles



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CRSS Hydrologies: Selected Ensembles



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CRSS Demands

- CRSS includes approximately 500 water users
- Representation of modeled water users varies by Basin
 - Upper Basin includes aggregated water users delineated by sector, such as agricultural, municipal & industrial (M&I), transbasin exports, Tribal, additional losses, etc.
 - Lower Basin includes all mainstream entitlement holders
- Monthly depletion and diversion projections are required as CRSS inputs for each water user
- Modeled depletion: model attempts to meet Diversion Requested and Depletion Requested with available water

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CRSS Demands: Current Representation

- **Upper Basin**
 - Developed by the Upper Colorado River Commission (UCRC), which provides decadal depletion demand schedules by water use sector at a state level
 - Updated 2016 UCRC Demand Schedule: disaggregated with cooperation from the Upper Basin States
 - Tribal demands are based on the 2018 Tribal Water Study
- **Lower Basin**
 - Derived from 2007 Interim Guidelines Final Environmental Impact Statement schedules with minimal updates made at the request of specific Lower Basin water users
 - Annual demands reflect Lower Basin state apportionments and Mexico's allocation

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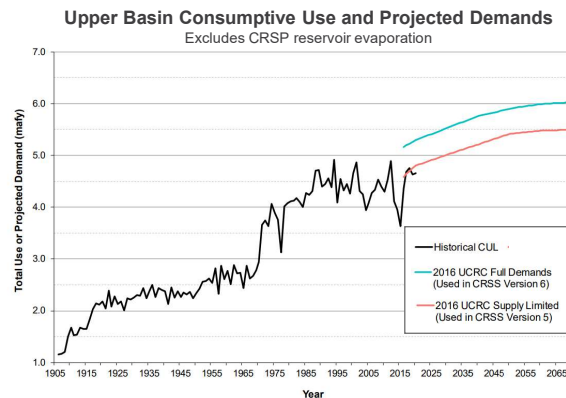


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CRSS: Upper Basin Demands

- CRSS v6 now uses the higher “full” demands projected by UCRC, but those demands are only satisfied if the simulated supply is sufficient at each node in the model
- This methodology has been calibrated and provides a more realistic representation of supply & demand
- This removes some of the previous concerns about projected demands being overstated



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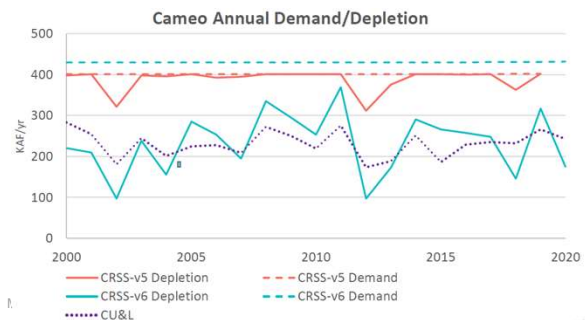
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CRSS: Upper Basin Demands

- Calibration with full demands (v6) reduces streamflow bias
 - Generally, decreases agricultural depletions which increases streamflow
- Calibration and full demands more accurately characterize Upper Basin depletions under a broad range of water supply conditions over the verification period

Model Version Update	Lake Powell Inflow		
	MAE* (kaf)	Bias (kaf)	% Bias
April 2020 CRSS w/ 2007 UCRC Demands	542	-535	-6%
August 2020 CRSS w/2016 UCRC Demands	332	-314	-3%
January 2022 CRSS w/2016 UCRC Demands	260	-145	-2%
March 2023 CRSS w/2016 Updated UCRC Demands	303	0	0%

*Mean Absolute Error



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CRSS Initial Conditions and Policies

- Results are sensitive to initial reservoir contents, particularly in the first decade
- Reservoir operations and water deliveries are approximated using rules and functions in the model
 - Collectively, the rules and functions make up a 'ruleset'
- To model decades into the future, rulesets make assumptions about future operating policies
- All policies must be able to be expressed in model rule logic

Ruleset Example – Powell Operations (Current)

Powell Rules		Policy Group
✓	Check Reservoir Capacity	18 Rule ✓
✓	Add Carryover Equalization Release	19 Rule ✓
✓	Equalization Tier	20 Rule ✓
✓	Upper Elevation Balancing Tier Jan thru March	21 Rule ✓
✓	Upper Elevation Balancing Tier April thru Sept	22 Rule ✓
✓	Mid Elevation Release Tier	23 Rule ✓
✓	Lower Elevation Balancing Tier Constrained	24 Rule ✓
✓	Lower Elevation Balancing Tier	25 Rule ✓
✓	Meet Powell Min Objective Release	26 Rule ✓
✓	Powell Limit Outflow Rule	27 Rule ✓
✓	Powell Smooth July Operation Rule	28 Rule ✓
✓	Powell Spike Flow Rule	29 Rule ✓
✓	Powell Operations Rule	30 Rule ✓
✓	Estimate Upper Basin Storage	31 Rule ✓
✓	EDWYStorageForecasts	32 Rule ✓

```

Arguments: [STRING res, DATETIME time]
IF (time == @StartTimestep - 1) THEN
  GetEffectiveStorage (res, @StartTimestep - 1)
ELSE
  IF (res == "Head") THEN
    HeadEffectiveStorage (time)
  ELSE IF (res == "Powell") THEN
    PowellEffectiveStorage (time)
  ELSE
    STOP_RUN "Invalid Reservoir passed to GetEffectiveStorage0"
  END IF
END IF
  
```

```

Lower Elevation Balancing Tier
Powell.Outflow ( )
  IF (Compare Powell and Head previous EDDC instead of Forecasted EDDC)
    IF (LowerElevationBalancingTier ( )) THEN
      Powell.Outflow ( )
      Powell.Inflow ( )
      Powell.ComputeStorageActiveOutflow
      ComputePowellReleaseBalancing
      In the additional check required because balancing releases made until dead pool
      ConvertPowellReleaseBalancing
      ConvertPowellReleaseBalancing
      (EqualizationData.ForecastEDDYPowell ( ), )
      IF (res == "Head") THEN
        "Head"
      ELSE IF (res == "Powell") THEN
        "Powell"
      ELSE
        "Error"
      END IF
    END IF
  END IF
  Conditional Operation LowerElevationBalancingTier ( ) THEN
    1.00
    ELSE
    0.00
  END IF
  
```



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CRSS: Lower Basin Alternative

- For Lower Basin Alternative development, all policies were tested against consistent **initial conditions, hydrology ensembles, and demands**
 - CRSS simulations ran from 2024 to 2057/2060 and were initialized with November 2023 conditions
- ADWR & CAP developed a rigorous process of collaborating on policy iterations, running CRSS v6, processing output files, QA/QC, and building consistent visualizations to effectively communicate policy impacts to our agency negotiators
- ADWR & CAP have run >100 policy iterations (to date), using the latest distribution of CRSS v6



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Technical Vulnerabilities in 2007 Interim Guidelines

- Operational decisions based on forecasts
- Single reservoir contents determining reductions
- Use of tiers for operations and shortage determinations
- Insufficient reduction volumes

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Technical Vulnerabilities: Operational Decisions based on Forecasts

- Current guidelines are based on Bureau of Reclamation's 24-month studies
 - 24-month studies are used to project reservoir operations and conditions for the next 24-month period
- Operations and shortage determinations are highly dependent on hydrology forecasts and water use projections, which are increasingly difficult to predict in a changing climate
- Hydrology in the 24-month studies does **not fully capture the risks of ongoing aridification of the Colorado River Basin** and water-supply planning ought to better anticipate the risks of decreasing inflows to Lake Powell

Paradigm Shift

Rely on measured conditions, incorporating hydrology that has happened, rather than what could happen

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Technical Vulnerabilities: Single Reservoir Contents Determining Reductions

- Current guidelines rely on Lake Mead elevations to make shortage determinations
- Thus, the link between **Powell release operations** and **Lake Mead elevations** is magnified, and subsequent operational decisions can have inadvertent consequences
- Focus on Lake Mead elevation only does not provide an adequate gauge of Colorado River Basin **system health**, a lesson learned in May 2022, when emergency actions were necessary to protect critical elevations at Lake Powell

Paradigm Shift

Base operations and reduction determinations on a **system contents approach**, which is a more holistic indicator of system health and allows for proactive instead of reactive responses to risk

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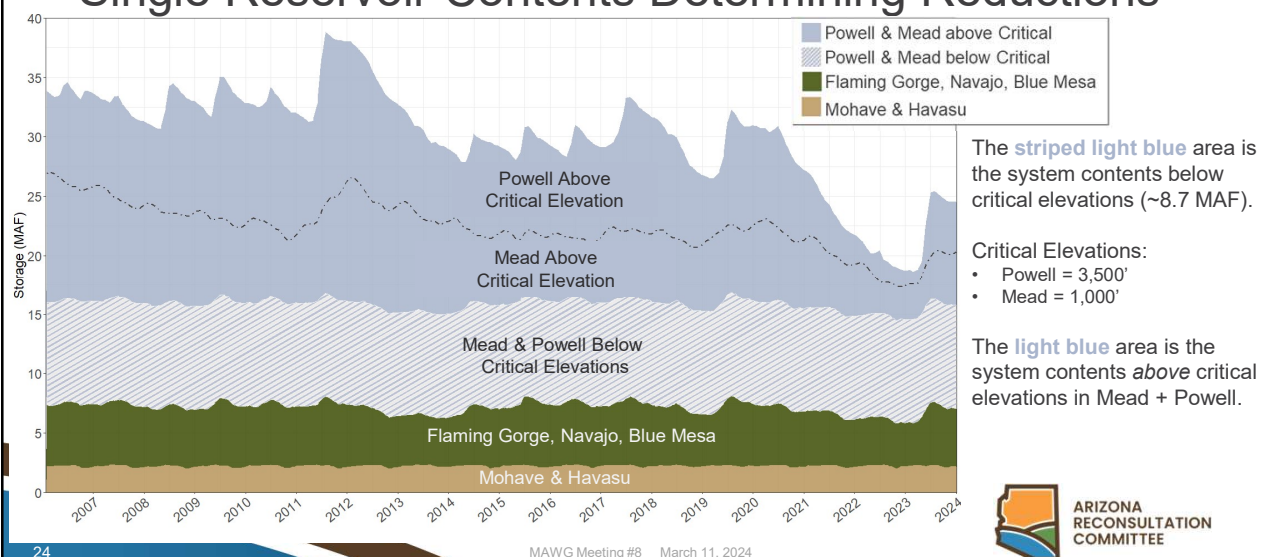
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Technical Vulnerabilities: Single Reservoir Contents Determining Reductions



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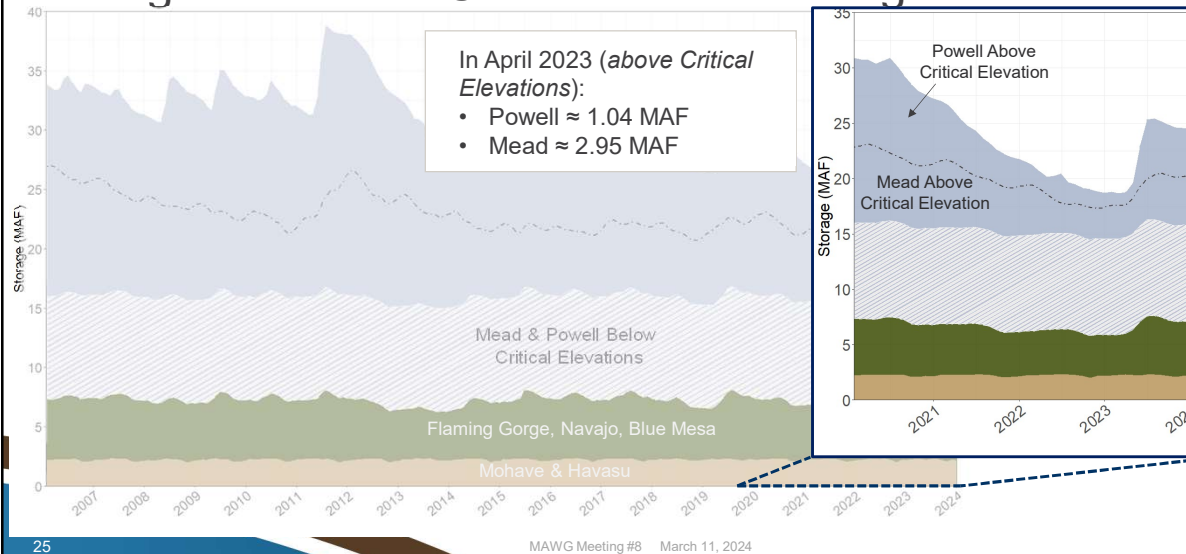
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Technical Vulnerabilities: Single Reservoir Contents Determining Reductions

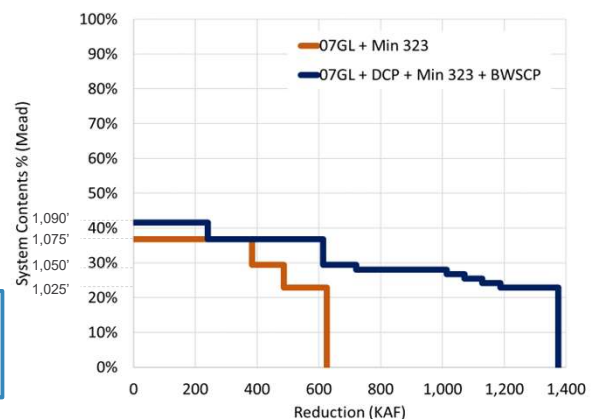


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Technical Vulnerabilities: Tier Basis for Operations and Shortage

- Current guidelines rely on narrow band of elevation-based triggers and tiers to specify shortages
- Consequently, one foot higher or lower in Lake Mead can have a substantial impact on reductions the next year

Paradigm Shift
Base reduction determinations on a **continuous function**, instead of categorized tiers



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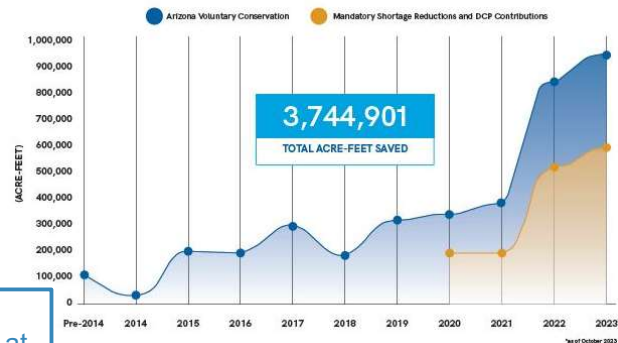
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Technical Vulnerabilities: 2007 Interim Guidelines Reduction Volumes

- During the interim period, additional actions have been needed to avert critical system conditions
 - Drought Contingency Plan
 - 500+ Plan
 - May 2022 Operational Adjustments
 - Supplemental Environmental Impact Statement (released March 5, 2024)



Paradigm Shift

Take proactive reductions before the system is at higher risk and take larger basin-wide reductions if needed to avert crisis

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Lower Basin Alternative: Goals

- Address the structural deficit in the Lower Basin
- Share the risks and benefits of the system within and between the basins
- Improve predictability of reductions to stabilize Lake Mead
- Improve water supply predictability over a broad but plausible range of future conditions

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Elements of the Lower Basin Alternative

- Water use as a function of the system contents approach
 - Surplus, Normal and Reduction conditions
- Lake Powell releases to Lake Mead
 - Equalization, "hydrologic shortage" based release, reduced and static releases
- Storage and delivery of conserved and augmentation water

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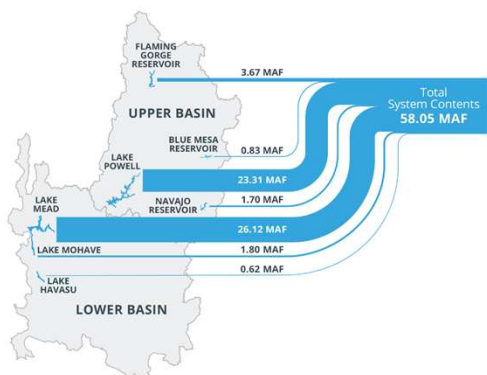


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Alternative Components and Design: Reductions

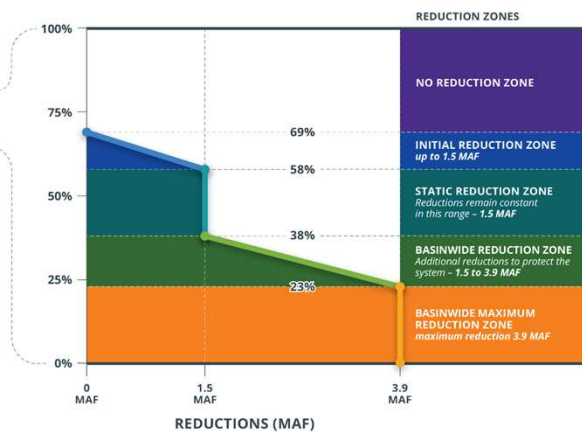
MAXIMUM SYSTEM CONTENTS

System contents are based on the volume in each reservoir that is available for release, in millions of acre-feet (MAF)



REDUCTION DETERMINATION

Reductions are based on the available system contents, based on the function below



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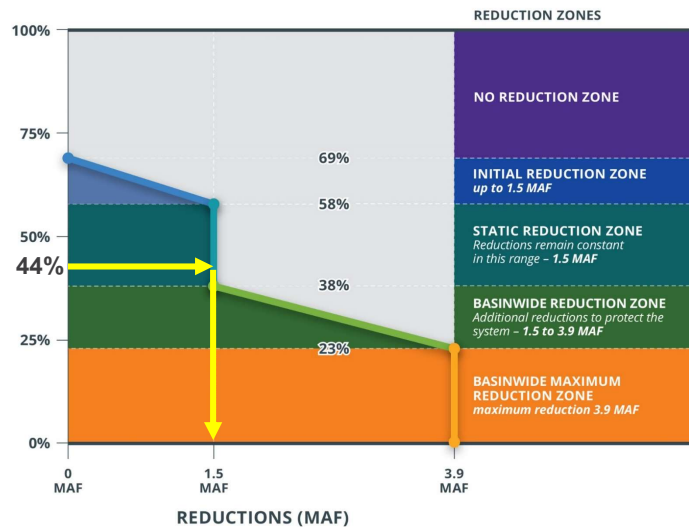
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Reduction Determination

As of August 1, 2023

Lake Powell	9.31 MAF
Lake Mead	8.50 MAF
Flaming Gorge Reservoir	3.32 MAF
Blue Mesa Reservoir	0.74 MAF
Navajo Reservoir	1.26 MAF
Lake Mohave	1.71 MAF
Lake Havasu	0.59 MAF
	25.42 MAF

$$\frac{25.42 \text{ MAF}}{58.05 \text{ MAF}} \times 100\% = 44\%$$



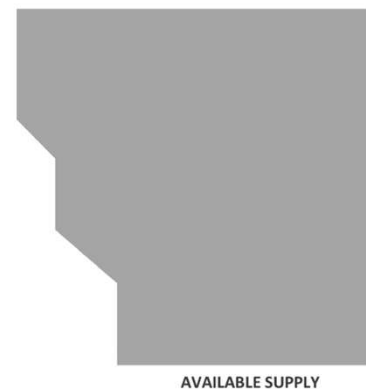
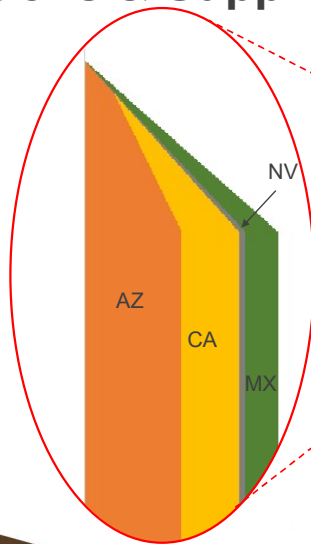
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Reductions & Supplies



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Reduction Sharing among Basin States & Mexico

	Total Reduction Volumes	Upper Basin	Arizona	California	Nevada	Mexico*
Initial Reduction Zone	Up to 300 KAF	0	80% (Up to 240 KAF)	0	3.33% (Up to 10 KAF)	16.67% (Up to 50 KAF)
	300 KAF – 1.5 MAF	0	43.33% (240 KAF – 760 KAF)	36.67% (0 KAF – 440 KAF)	3.33% (10 KAF – 50 KAF)	16.67% (50 KAF – 250 KAF)
Static Reduction Zone	1.5 MAF	0	760 KAF	440 KAF	50 KAF	250 KAF
Basin-wide Reduction Zone	1.5 – 3.9 MAF	Shared among Upper Division states, Lower Division States and Mexico				
Basin-wide Maximum Reduction Zone	3.9 MAF					

*Reductions to Mexico will be determined in a separate binational process



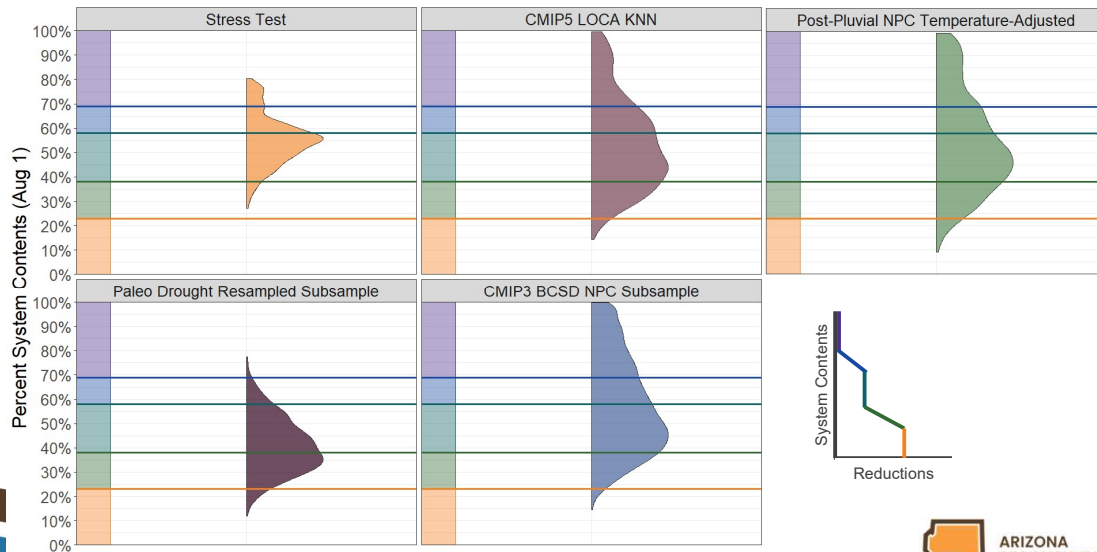
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Results: Reductions



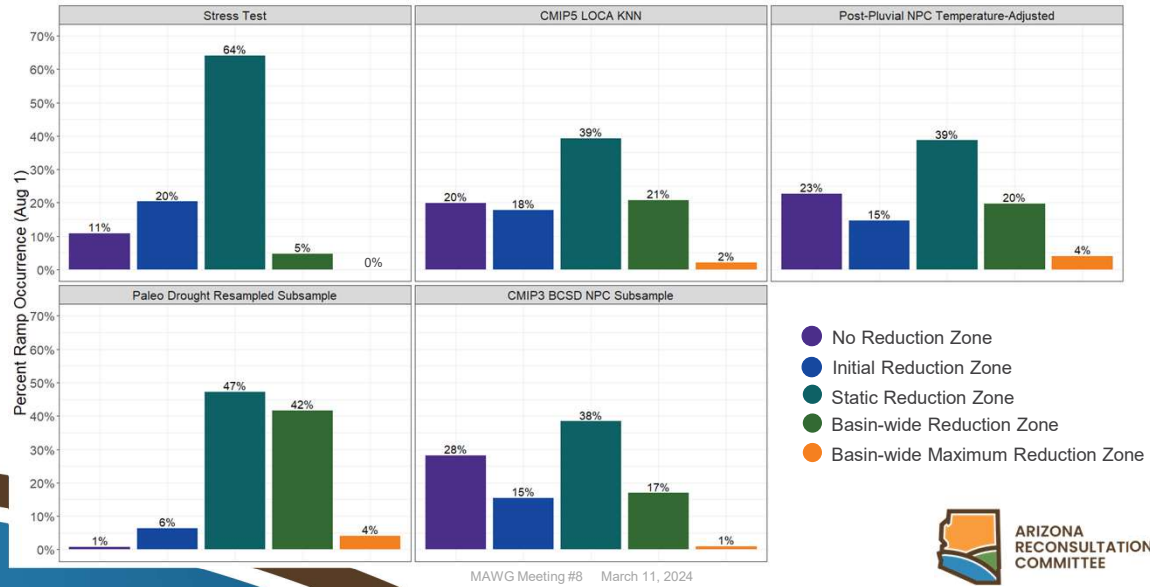
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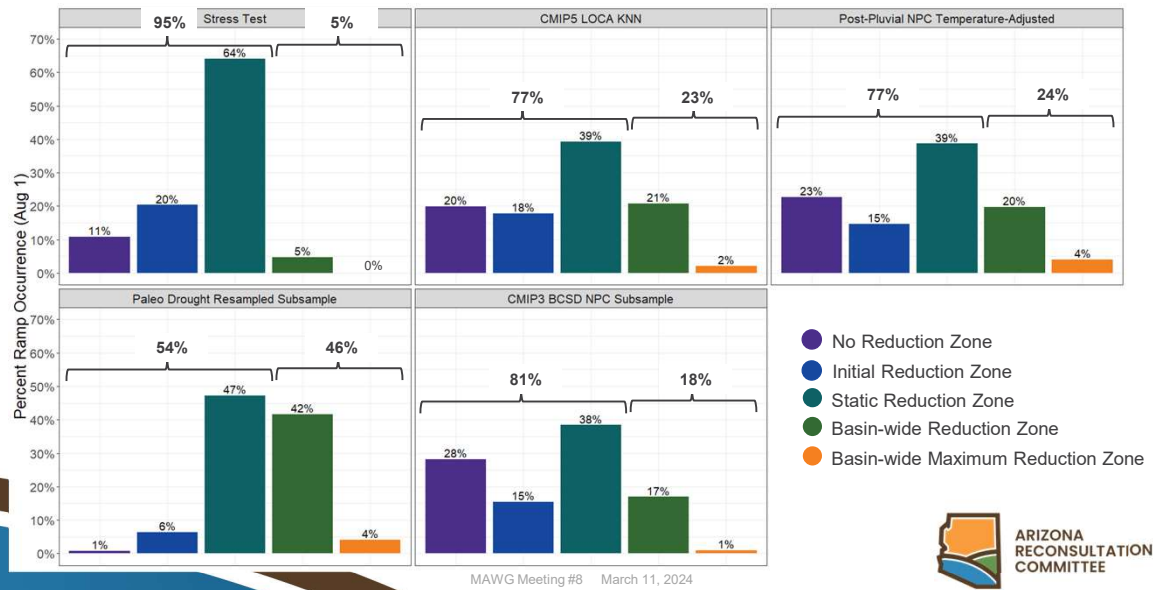
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Results: Reductions



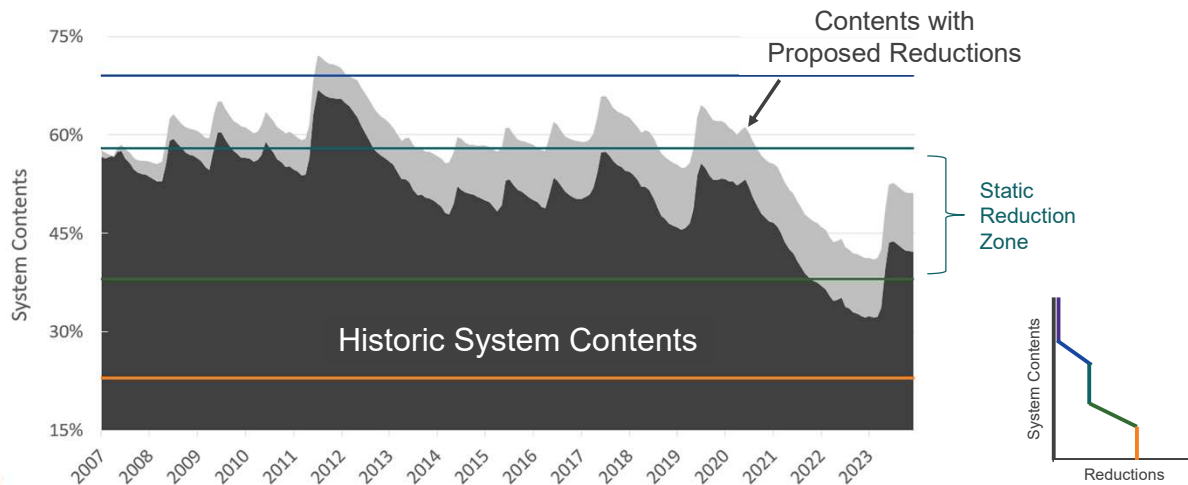
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Results: Reductions



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Results: Reductions



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BOR Metrics and Robustness

- BOR will be evaluating alternatives as developed for NEPA process
- BOR will evaluate performance, tradeoffs, robustness and vulnerability of all potential alternatives that will be considered in Draft EIS and Final EIS
- All alternatives will be tested against the same BOR defined **initial conditions**, **hydrology ensembles**, and **demands**



[Post-2026 Operations Exploration Web Tool](#) | [Bureau of Reclamation \(usbr.gov\)](https://www.usbr.gov)

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MAWG Next Steps

- Lower Basin Alternative Additional Components
 - Powell Releases
 - Shortage Programs
 - Surplus Conditions
- Intra-Arizona Analysis
- Analysis of Other Alternatives
- MAWG #9 will be held Late March/Early April 2024 at CAP Headquarters

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Discussions/Questions

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