BUREAU OF RECLAMATION

CRSS Modeling Enhancements to Support Long-Term Planning in the Colorado River Basin

RiverWare User Group Meeting

August 29, 2023

Changed Circumstances Since Adoption of the 2007 Interim Guidelines

- Unprecedented drought, exacerbated by climate change, and declining reservoir storage
- **Increasing uncertainty about future water supply and demand**
- Need to explore a wide range of creative solutions
- Advances in technical methods and tools
- Increased need for expanded partner-stakeholder engagement in Colorado River decision-making

These factors are described in the June 2022 Federal Register Notice requesting input on the development of Post-2026 Colorado River Reservoir operational strategies for Lake Powell and Lake Mead

Challenges of Planning under Deep Uncertainty

- Deep uncertainty (broadly defined) exists if
  1. It is impossible to determine the most appropriate planning assumptions;
  2. There is no universally agreed upon way to balance different system priorities; or
  3. Stakeholders disagree about how to best represent the system in a model.

- **In the Colorado River Basin**, 1 & 2 are major challenges[1]
  - Climate change is impacting hydrology and there is no scientific agreement on the best representation of supply
  - Future demands are uncertain
  - Water must be shared across many diverse Basin resources and interests

- Most previous planning efforts have relied primarily on achieving an acceptable level of "risk", i.e., percent of traces that have a bad outcome
  - Completely dependent on the chosen ensemble of hydrology traces and other assumptions
  - Changes over time as the system responds to new conditions
  - Can be particularly problematic when reservoirs are near important thresholds

Decision Making under Deep Uncertainty

Decision Making under Deep Uncertainty (DMDU) methods incorporate concepts and tools that can help address the Basin's unprecedented planning challenges[1]

Key Elements

- Consider a *wide range* of future conditions without assigning likelihood beforehand
- Prioritize *robustness*, or the ability of a policy to perform acceptably well in a wide range of conditions
- Assess the *vulnerability* of a policy: what uncertain future conditions might cause it to perform poorly?

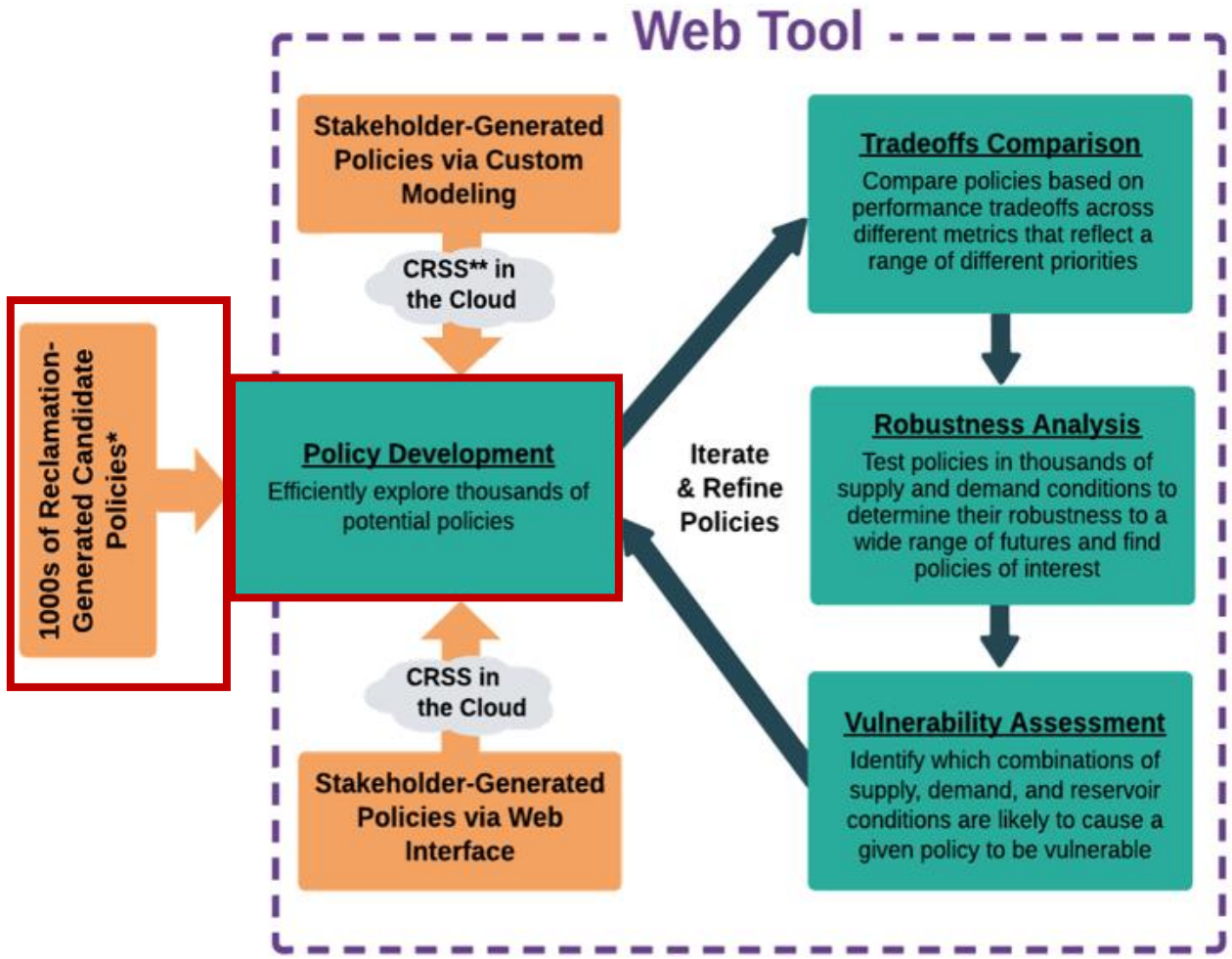
Benefits

- Eliminates the need to choose specific hydrology and demand assumptions at the beginning of a planning process
- Helps prevent misperceptions of low risk that can accompany probabilistic analyses
- Encourages dialogue about balancing priorities and preferred vs. acceptable levels of performance
- Facilitates ability to adapt based on observable conditions as they unfold

Post-2026 is using the Many Objective Robust Decision Making (MORDM)[2] framework to apply DMDU methods—including the BORG MultiObjective Evolutionary Algorithm (MOEA).

MORDM and the Post-2026 Web Tool

- Integrating key MORDM concepts in a CRB Post-2026 DMDU Web Tool (Web Tool)
  - Representation of uncertainty
  - Policy development
  - Tradeoff comparison
  - Robustness analysis
  - Vulnerability assessment
- Web Tool will be used to screen potential post-2026 operational alternatives
  - Designed for policy exploration and learning for a broad range of stakeholders with varying modeling expertise
- Focus on policy development & associated model enhancements



**Colorado River Simulation System, Reclamation's long-term planning model
*Candidate policies will be generated for purposes of modeling analysis

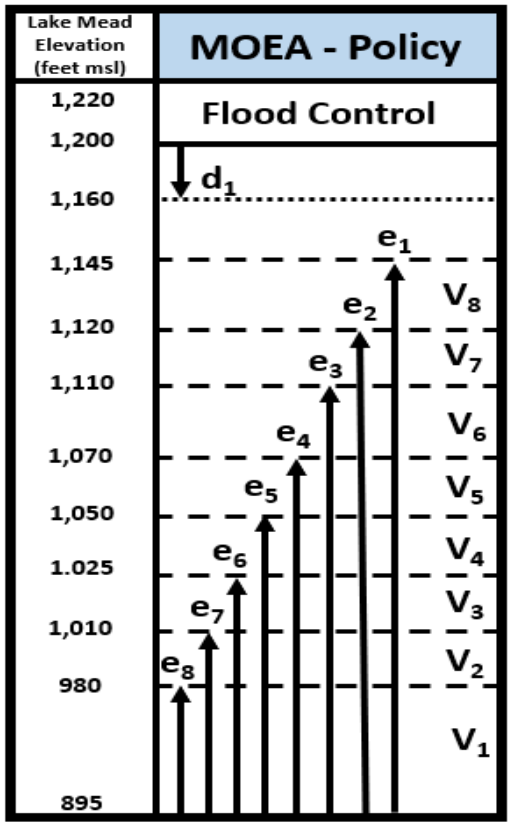
Tools to Support Post-2026 Policy Development

- A Web Tool policy is comprised of Lake Mead and Lake Powell operations
  - Lake Powell release triggers and volumes
  - Lower Basin shortage triggers and volumes
- Other operational considerations (e.g., voluntary conservation) will be fine-tuned during subsequent stages of alternative development
- Little consensus on future operations
  - Adjusting Lower Basin shortages or Powell releases based on recent hydrology
  - Use tiers or a linear function (based on reservoir elevation) to determine Powell releases and/or Lower Basin shortages
  - Lower Basin shortage triggers based on Mead pool elevation or combined storage
- Policies *must be* robust and adaptable
- **Requires**
  - Highly flexible and robust models
  - An efficient method to generate and test thousands of policies

Policy Development Using a MultiObjective Evolutionary Algorithm (MOEA) & CRSS

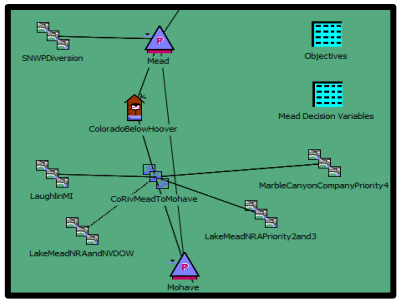
Policy Variables

Mead Tier Elevations
& Shortage Volumes

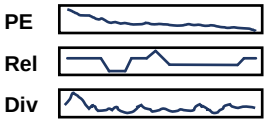


Input Hydrology & Demand Scenario

CRSS* Model



Model Outputs



Objective Functions (f_i)

measurements of
system performance

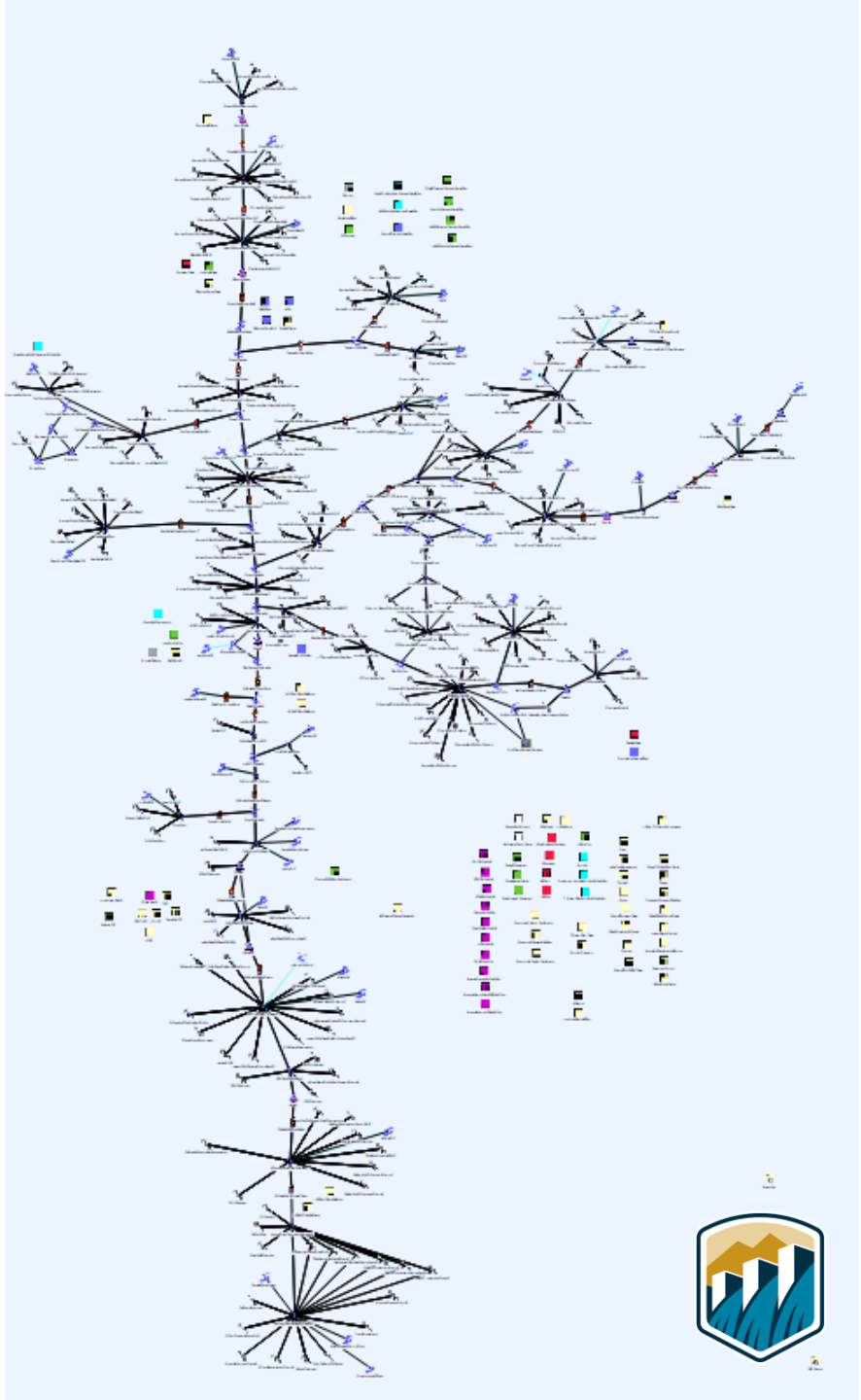
$f_1 \ \ldots \ f_8$

BORG-MOEA

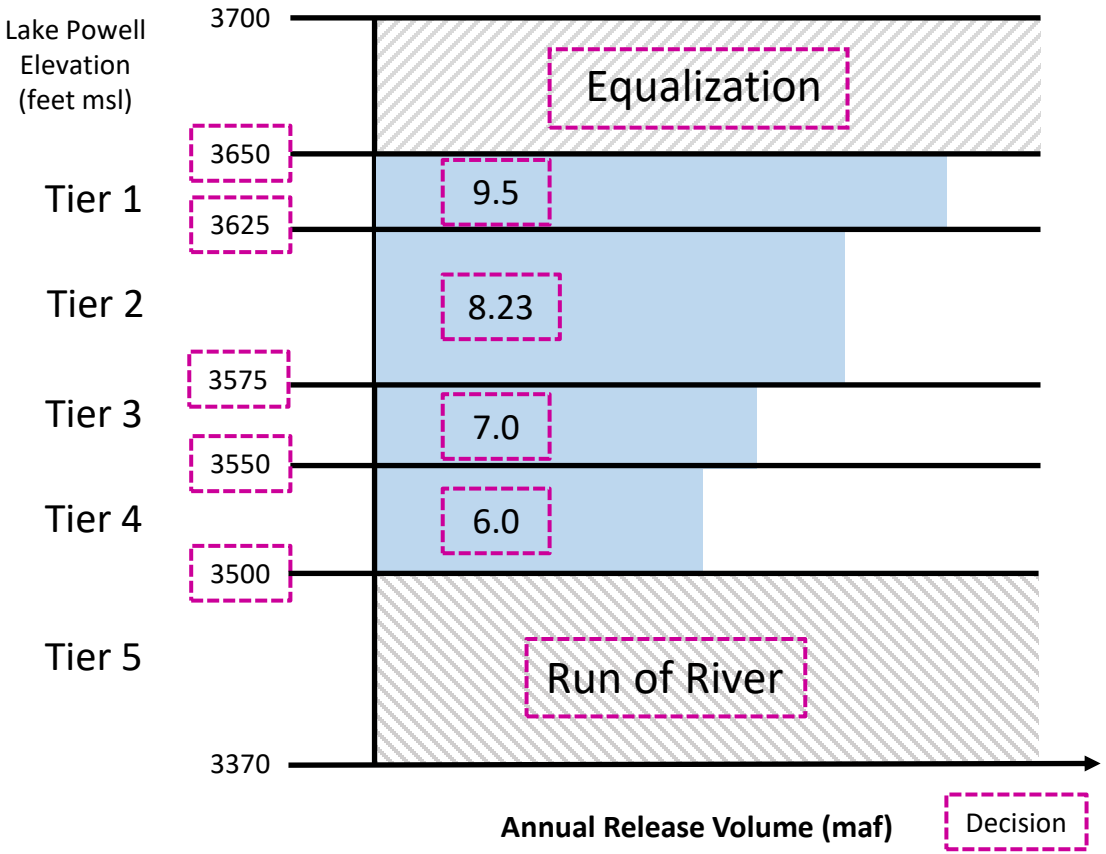
*Reclamation's long-term planning model that simulates the operation of major reservoirs on the Colorado River System

Web Tool Model Development

- Developed general operating paradigms and concepts with input from stakeholders
- A **paradigm** is a fundamental approach to Lake Powell and Lake Mead operations—specifically Powell releases and Lower Basin shortages
- Create multiple paradigm models using Reclamation's Colorado River Simulation System (CRSS) RiverWare model
  - Ex: Tiered Powell Releases + Tiered Lower Basin Shortages

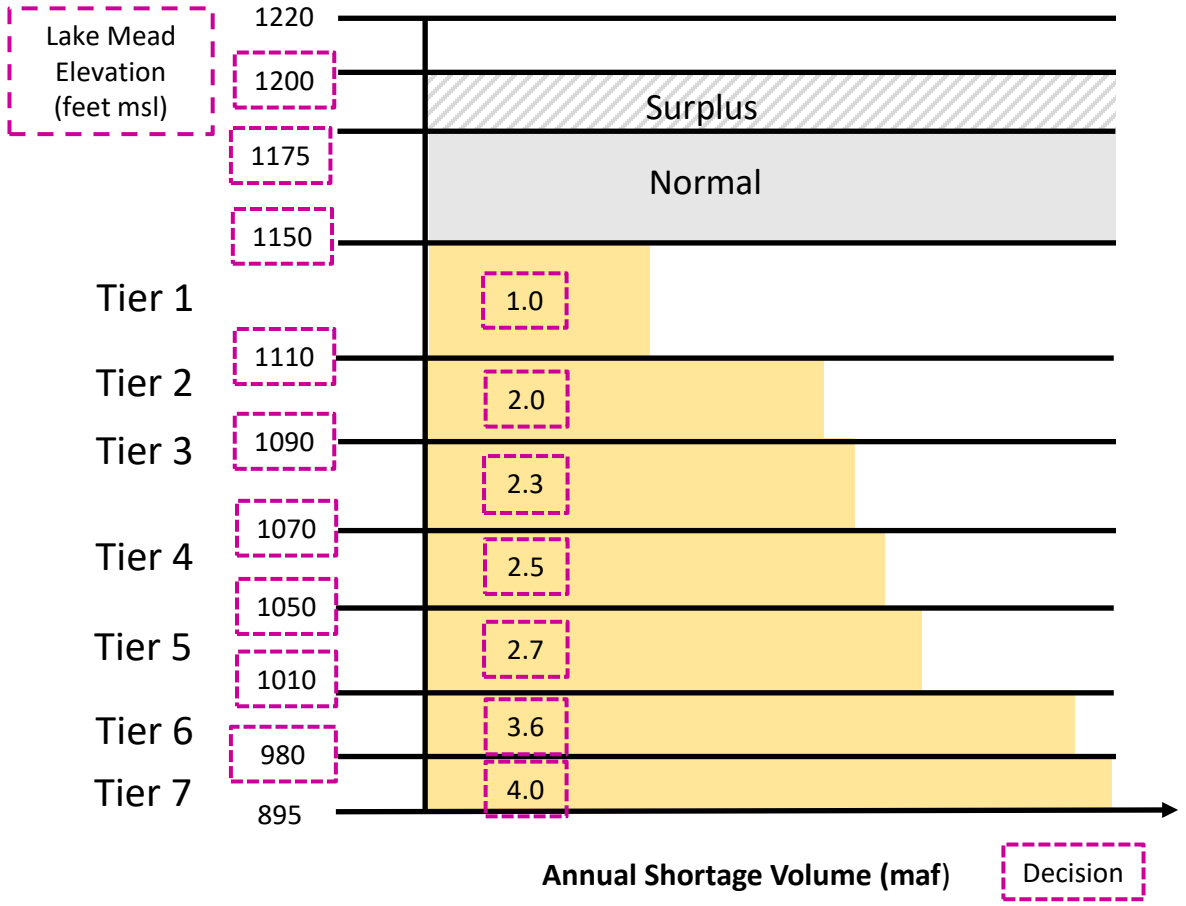


Tiered Powell Releases



- Max of 5 tiers + equalization tier
- Equalization tier is optional
- 2 ways to define equalization
- Can turn on coordinated operations or adjust Powell releases based on recent hydrology

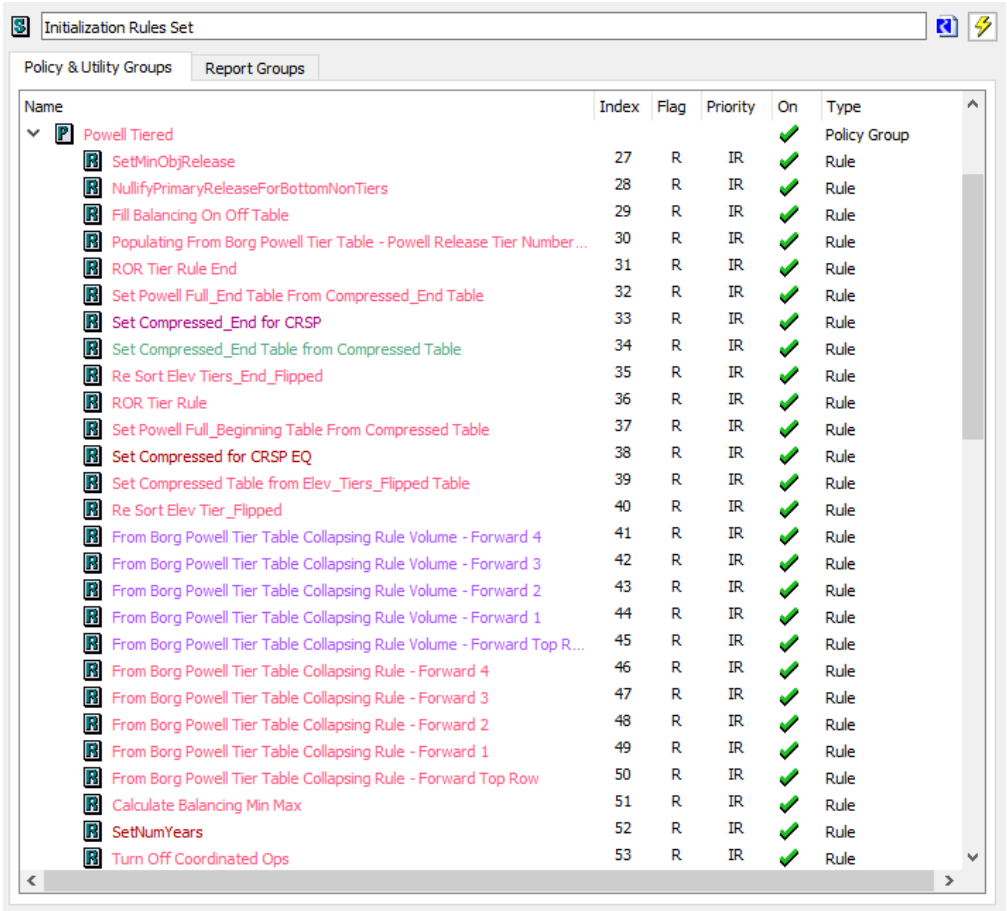
Tiered Shortage: Mead Elevation



- Max of 8 shortage tiers + surplus tier
- Surplus tier is optional
- Distribution of Lower Basin shortages is not represented in Web Tool modeling
  - Lake Mead releases are reduced as specified by a given policy, enabling analysis of reservoir levels

Required Model Changes

- Developed initialization rules to read in and manipulate decision variable output from BORG
  - Human readable compatibility with Web Tool
- Developed new rules and functions to accommodate decision variables and operating paradigms
- Modified existing rules and functions to accommodate decision variables
- Extensive use of tables
- Incorporated flags (via scalar slots) to turn options on/off



Name	Index	Flag	Priority	On	Type
Powell Tiered				✔	Policy Group
SetMinObjRelease	27	R	IR	✔	Rule
NullifyPrimaryReleaseForBottomNonTiers	28	R	IR	✔	Rule
Fill Balancing On Off Table	29	R	IR	✔	Rule
Populating From Borg Powell Tier Table - Powell Release Tier Number...	30	R	IR	✔	Rule
ROR Tier Rule End	31	R	IR	✔	Rule
Set Powell Full_End Table From Compressed_End Table	32	R	IR	✔	Rule
Set Compressed_End for CRSP	33	R	IR	✔	Rule
Set Compressed_End Table from Compressed Table	34	R	IR	✔	Rule
Re Sort Elev Tiers_End_Flipped	35	R	IR	✔	Rule
ROR Tier Rule	36	R	IR	✔	Rule
Set Powell Full_Beginning Table From Compressed Table	37	R	IR	✔	Rule
Set Compressed for CRSP EQ	38	R	IR	✔	Rule
Set Compressed Table from Elev_Tiers_Flipped Table	39	R	IR	✔	Rule
Re Sort Elev Tier_Flipped	40	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule Volume - Forward 4	41	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule Volume - Forward 3	42	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule Volume - Forward 2	43	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule Volume - Forward 1	44	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule Volume - Forward Top R...	45	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule - Forward 4	46	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule - Forward 3	47	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule - Forward 2	48	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule - Forward 1	49	R	IR	✔	Rule
From Borg Powell Tier Table Collapsing Rule - Forward Top Row	50	R	IR	✔	Rule
Calculate Balancing Min Max	51	R	IR	✔	Rule
SetNumYears	52	R	IR	✔	Rule
Turn Off Coordinated Ops	53	R	IR	✔	Rule

BORG Optimization Simulations & Results

- For each operational concept used in optimization
  - 1 modeled future operational concept
  - 8 hydrology traces (represents uncertainty)
  - 5 different starting positions for BORG (i.e., seeds)
  - 5,000 – 7,000 optimization runs per starting position

  Results in 200,000 – 280,000 RiverWare simulations per operational concept & approximately 200 – 800 non-dominated policies

- Running optimization on ~10 operational concepts
- Excludes robustness runs
- Made possible (in part) by cloud computing

References & Resources

1. *Decision Science Can Help Address the Challenges of Long-Term Planning in the Colorado River Basin* (JAWRA, 2022) https://onlinelibrary.wiley.com/doi/10.1111/1752-1688.12985
2. *Many objective robust decision making for complex environmental systems undergoing change* (Environmental Modeling & Software, 2013) https://www.sciencedirect.com/science/article/pii/S1364815212003131

- 2007 Interim Guidelines FEIS: https://www.usbr.gov/lc/region/programs/strategies/FEIS/index.html
- Reclamation's Post-2026 Website: https://www.usbr.gov/ColoradoRiverBasin/Post2026Ops.html
- June 2022 Federal Register Notice: Federal Register :: Request for Input on Development of Post-2026 Colorado River Reservoir Operational Strategies for Lake Powell and Lake Mead Under Historically Low Reservoir Conditions
- June 2023 Federal Register Notice: Federal Register :: Notice of Intent To Prepare an Environmental Impact Statement and Notice To Solicit Comments and Hold Public Scoping Meetings on the Development of Post-2026 Operational Guidelines and Strategies for Lake Powell and Lake Mead

Questions?

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