BUREAU OF RECLAMATION

Post-2026 Integrated Technical Education Workgroup Session 6: Web Tool Operational Paradigms and Uncertainties Follow Up

Virtual Session – November 2, 2023

The meeting will begin at 10:00 a.m., MDT

La interpretación en vivo será disponible en español. Live interpretation will be available in Spanish.

Dial In: (720) 928-9299 or (602) 753-0140; Meeting ID: 857 1121 4918

For technical support, please contact Megan Stone: megan.stone@empsi.com

Welcome & Introductions

- This is the 6th session of Reclamation's Integrated Technical Education Workgroup (kickoff session was December 7, 2022)
- The Technical Education Workgroup has been formed for the purpose of assisting our partners and stakeholders to gain a better understanding of the technical tools and approaches to be used in the Post-2026 process and help our partners improve technical capacity
- Workgroup "ground rule": Please refrain from publishing/posting presentation material until posted to Reclamation website
- Thank you for your participation in this Workgroup

Purpose of Technical Workgroup

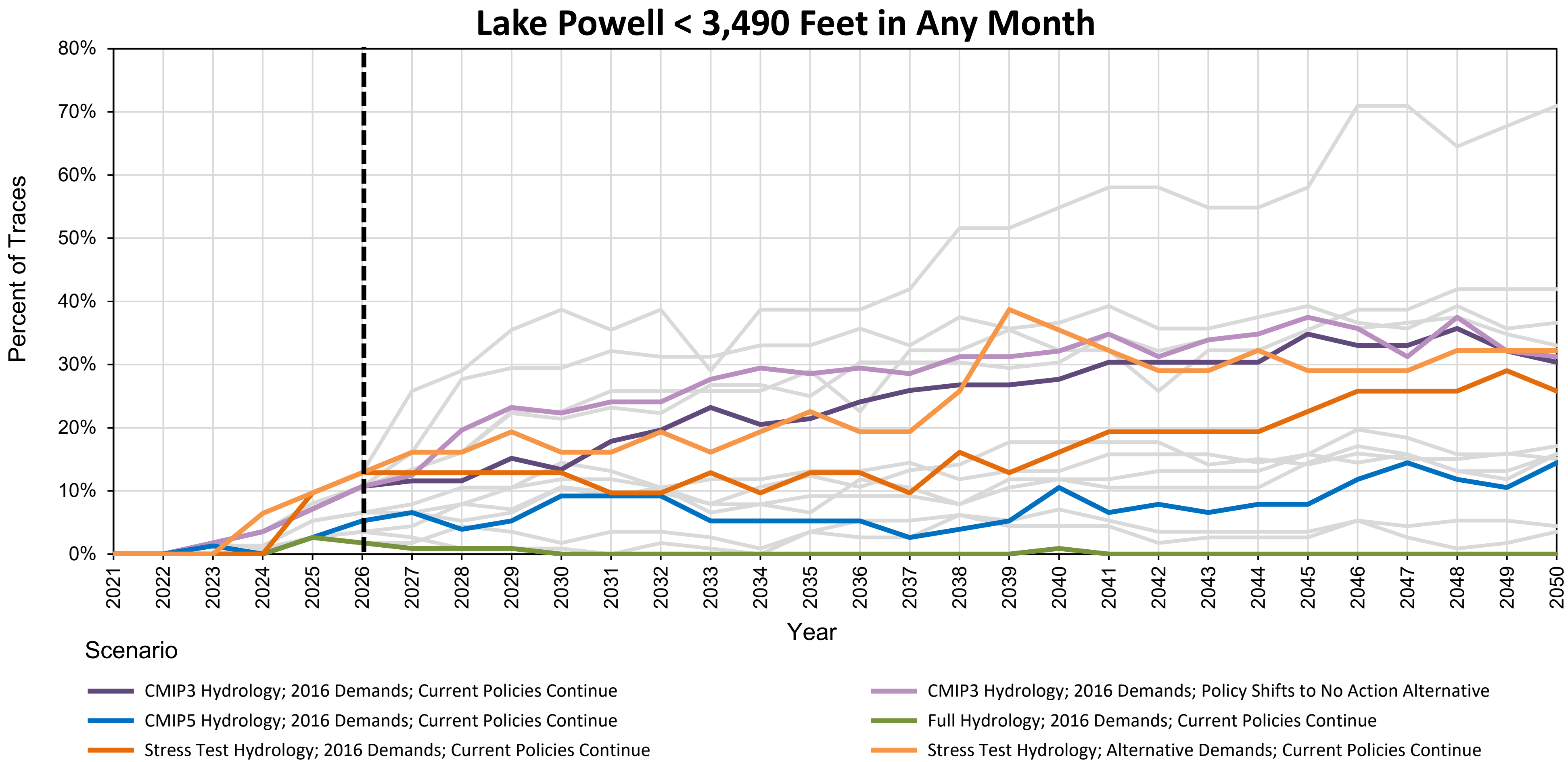
- The purpose of the Workgroup is for Reclamation to offer education about the technical approach, tools, and data frequently used in its long-term planning studies and to specifically share information about the technical framework that will support the Post-2026 Process
  - The Workgroup will be led through a set of technical education sessions throughout 2023
- The goal is to increase technical capacity and build a solid technical foundation to facilitate meaningful involvement in the Post-2026 Process
- The purpose of the Workgroup is NOT to develop operational alternatives for Post-2026 as a group or to discuss other non-technical aspects of the Process
  - There will be other opportunities to engage with Reclamation on those aspects in separate venues
- The Workgroup does not replace Reclamation's commitment to providing technical support to individual partners upon request

Agenda

- Review of Decision Making under Deep Uncertainty (DMDU) and the Post-2026 Technical Framework
- Alternative paradigms in the Post-2026 Web Tool
  - Background and introduction to alternative paradigms in Web Tool
  - Lake Powell Release concepts included in Web Tool
  - Lower Basin Delivery concepts included in Web Tool
  - Summary of supported paradigms
  - Seed strategies and multi objective optimization
- Choices for representing uncertainty in Web Tool modeling
  - Hydrology
  - Demands
  - Initial Conditions
  - Vulnerability Demo
- Wrap up and future sessions

Review of DMDU and the Post-2026 Technical Framework

Long-term risk outlooks using different supply, demand, and operational assumptions*



*All projections are from August 2020 CRSS modeling with Lake Powell initial elevation of 3,592’. Lake Powell’s current elevation is ~3,573’
CMIP5 ensemble based on BCSD downscaling

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 critical 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

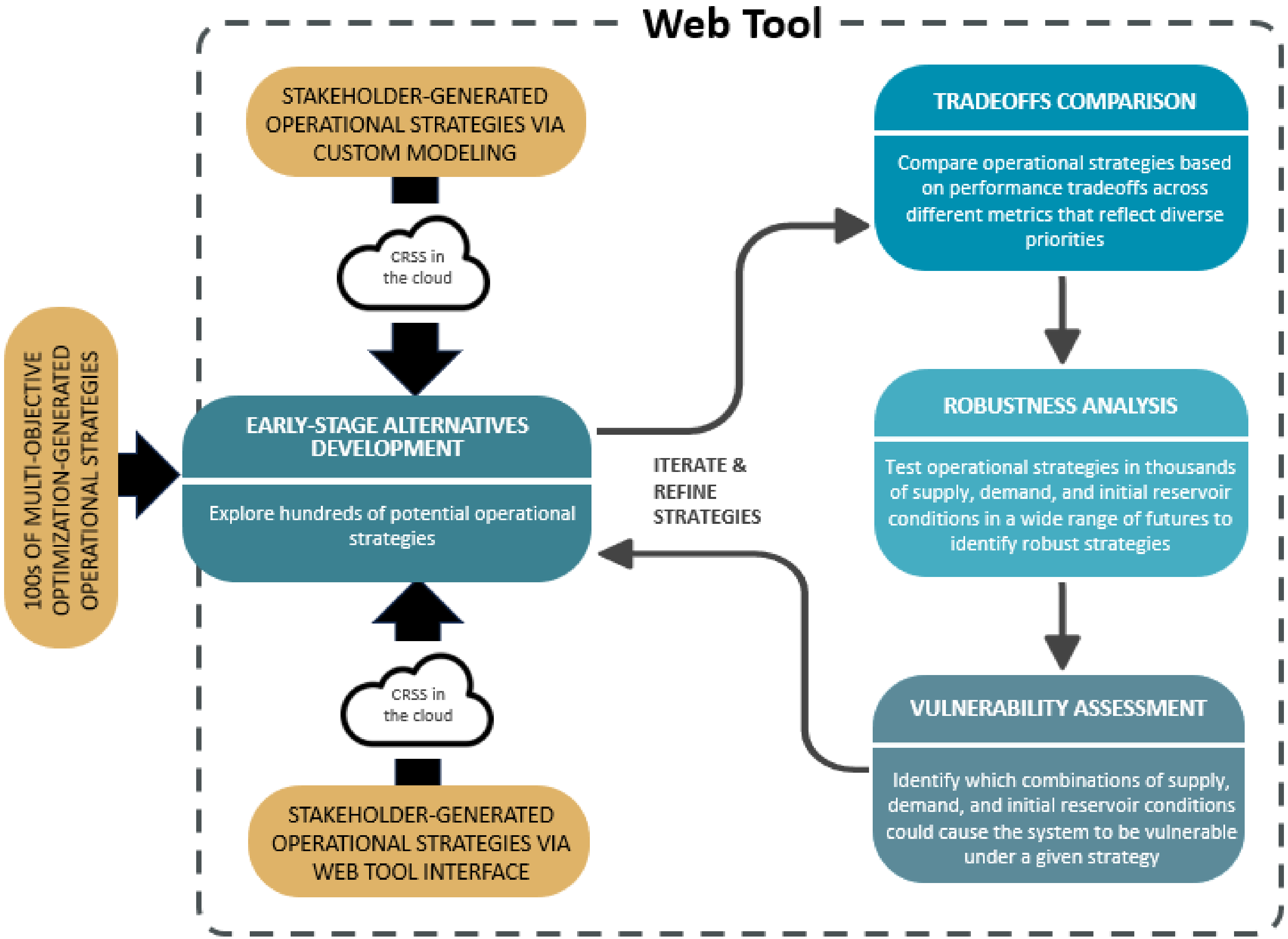
- Consider a *wide range* of future conditions without assigning likelihood beforehand
- Prioritize *robustness*, or the ability of an operational strategy to perform acceptably well in a wide range of conditions
- Assess the *vulnerability* of the system under an operational strategy: what uncertain future conditions might cause the system to have unacceptable performance?

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

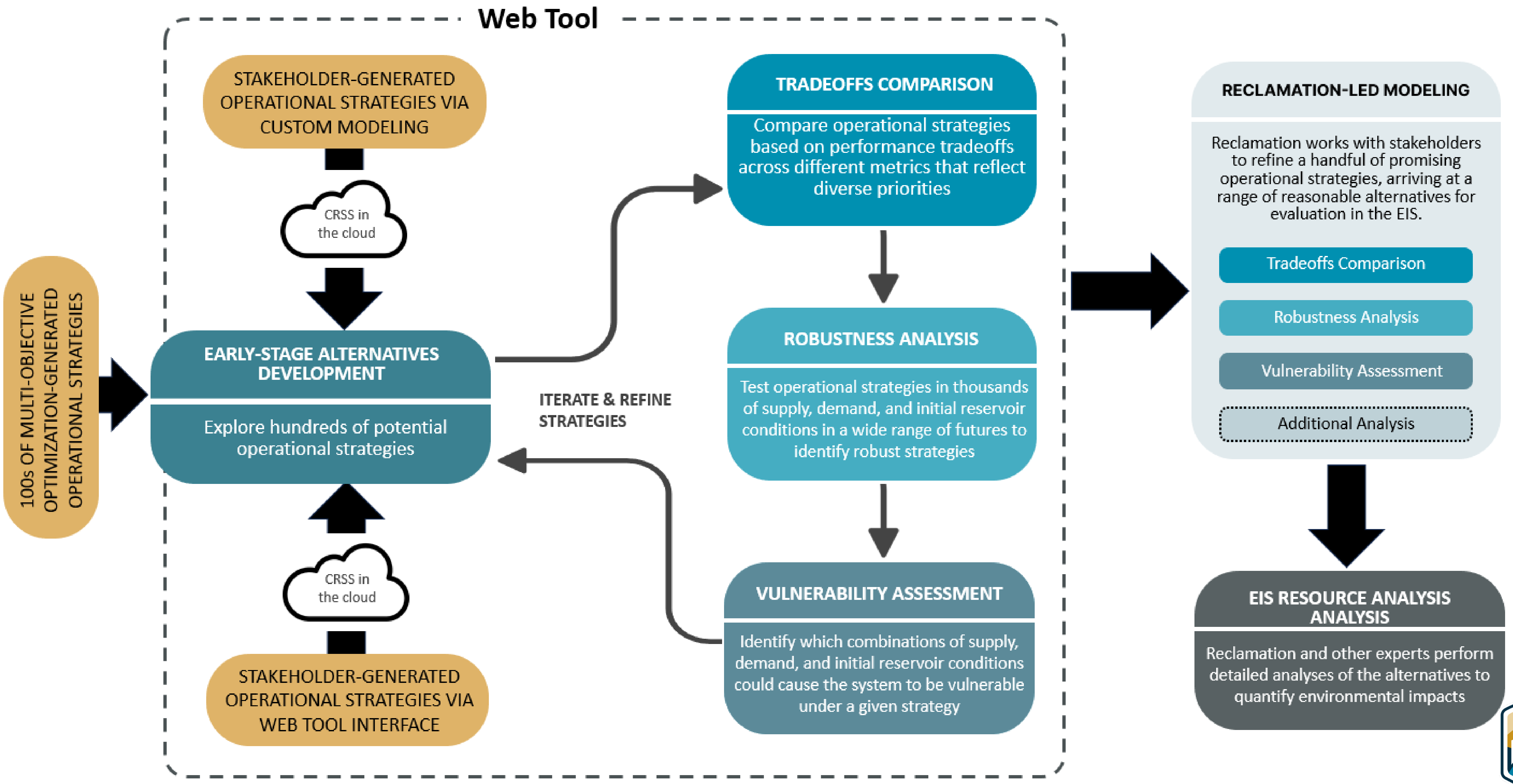
Different frameworks can be used to apply DMDU methods. Post-2026 is using Many Objective Robust Decision Making (MORDM)[2]

Many Objective Robust Decision Making (MORDM) in the Post-2026 Operations Exploration Web Tool



- **User-friendly interface connected to CRSS**
  - Create operational strategies that are formatted and sent to CRSS
  - Interact with output from CRSS simulations
- **Inclusive**
  - No prior experience with CRSS is required to create and explore operational strategies
  - Compatible with stakeholders who perform advanced modeling
  - Facilitates collaboration
- **Transparent**
  - Common technical platform
  - Consistent information
- **Best available science**
  - Provides in-depth DMDU information and education
- **Screening tool**
  - Important to present a variety of metrics to engage a diverse set of stakeholders and support analysis
  - Many implementation details of policies will be addressed in later stages of alternative development

MORDM & the Web Tool in the Post-2026 Process



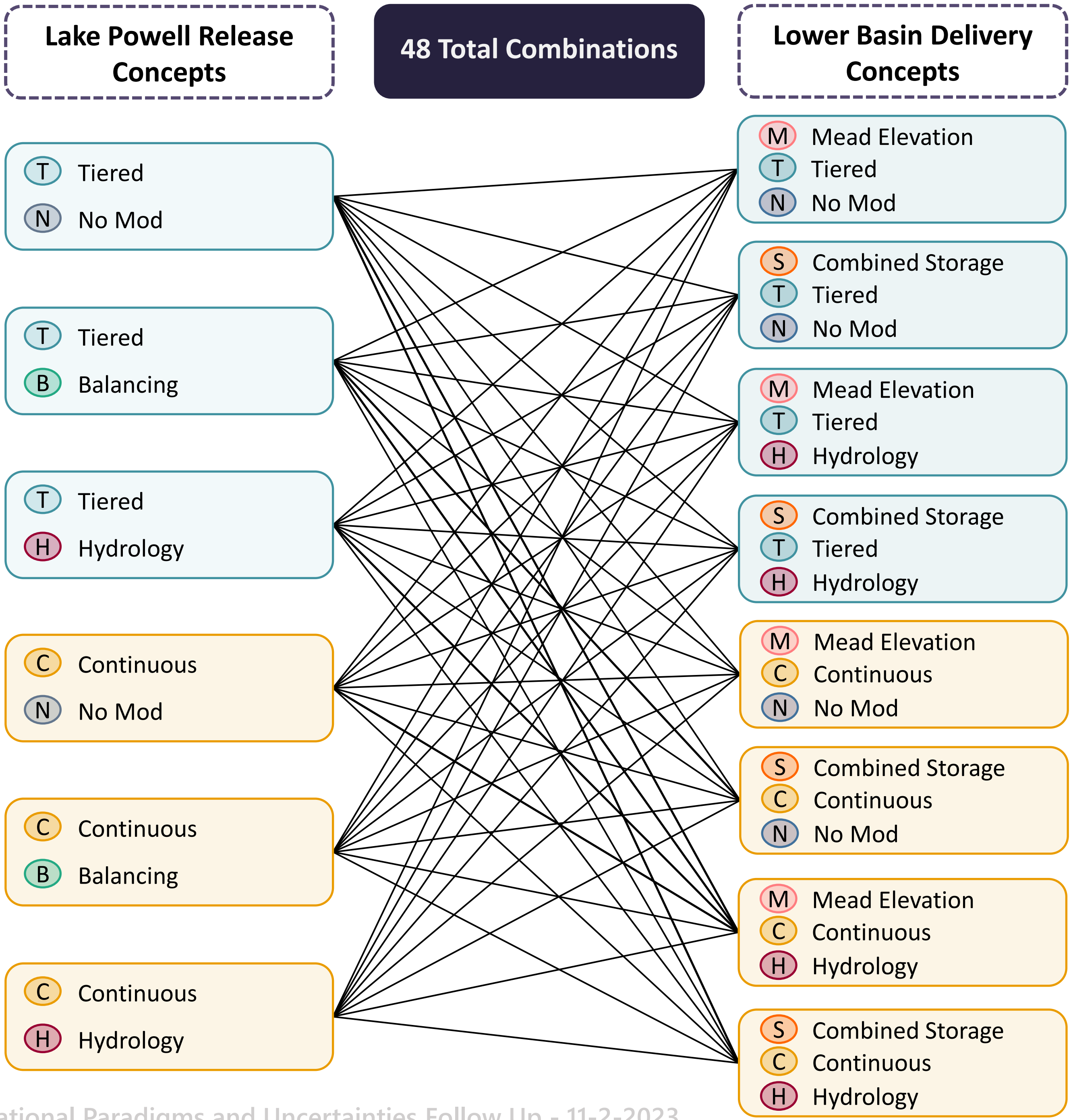
Paradigms and the Post-2026 Web Tool

Introduction to Operational Paradigms

- Through the Post-2026 Scoping (and Pre-scoping) periods, many comments were received suggesting specific "operational paradigms" for consideration
- Reclamation used this input and analytical approaches to select the paradigms that come built-in the Web Tool
- The paradigms allow users to explore various operational strategies for Lake Powell and Lake Mead operations
  - The focus of the Web Tool is Lake Powell release and Lower Basin delivery concepts
    - Provides insight into the performance of various operational strategies and the volumes of conservation or water use reductions needed to stabilize the system
  - More detailed exploration, for example, storage and delivery of conserved water in Lake Mead and/or Lake Powell needs to be explored outside of the Web Tool
- **Exploration of an operational strategy in the Web Tool = Exploration of an operation strategy in CRSS(v6)**
- **The Web Tool does not display any information about the source/user that created any operational strategy.**

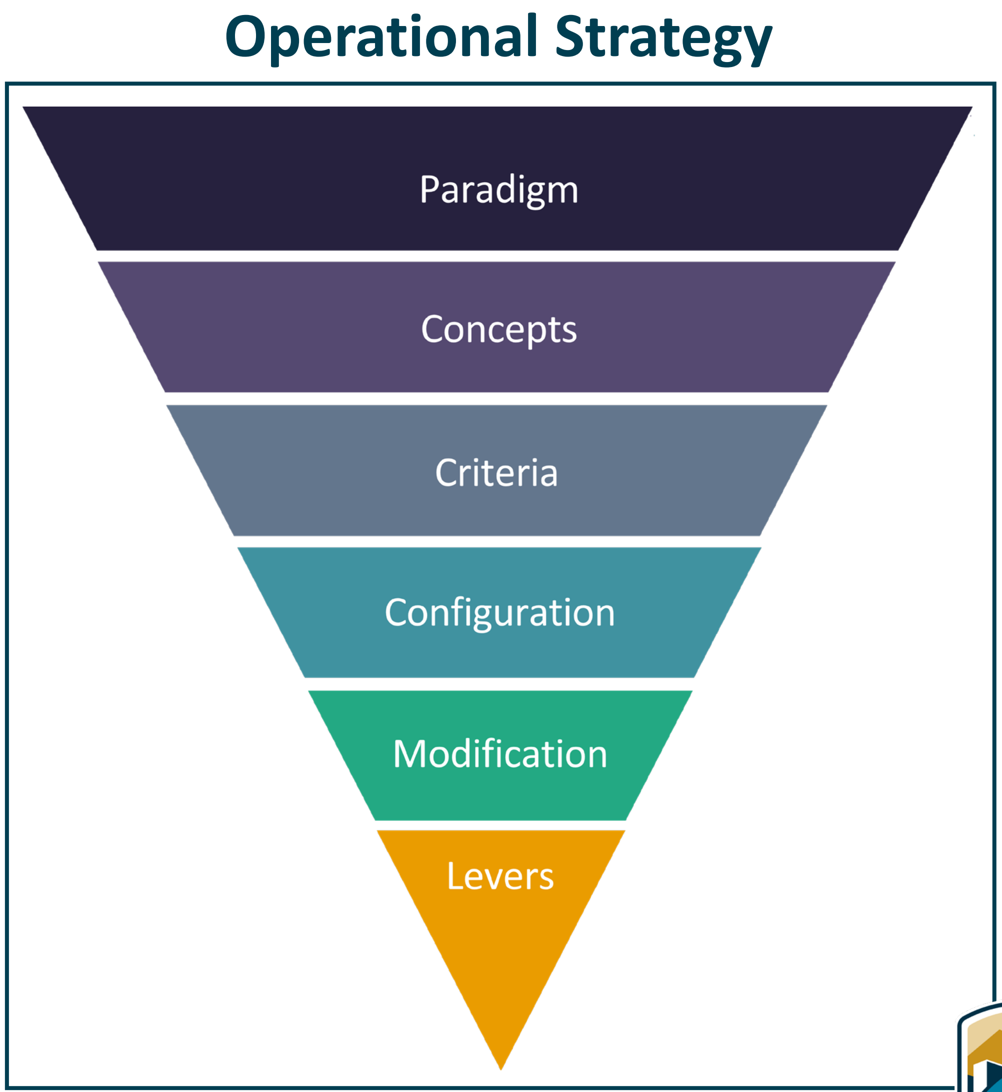
Scope of Operational Strategies in Web Tool

- Defined as different combinations of:
  - **6 Lake Powell Release Concepts:** Triggers and annual volumes of releases from Lake Powell
  - **8 Lower Basin Delivery Concepts:** Triggers and annual volumes of deliveries (or delivery reductions) from Lake Mead to Lower Basin
- Does not include operations at other reservoirs, voluntary conservation activities, distribution of shortages by user, or other implementation details (these issues will be addressed in later stages of alternatives development)



Web Tool Terminology & Structure

- **Operational strategy:** specifies Lake Powell and Lake Mead operations
- **Paradigm**: a unique combination of 2 concepts that define Lake Powell releases & Lower Basin deliveries
- **Concepts:** used to define Lake Powell releases & Lower Basin deliveries—based on criteria, configuration, and release modifications
- **Criteria**: basis for determining annual Lower Basin deliveries (Lake Mead operations only)
- **Configuration:** type of function used to define Lake Powell releases and Lower Basin deliveries
- **Release or Delivery Modification:** additional factors that can modify annual Lake Powell release volumes or Lower Basin deliveries
- **Levers:** user-defined values that complete the definition of an operational strategy



Paradigm

A unique combination of 2 concepts that define Lake Powell releases & Lower Basin deliveries

Lake Powell Release Concept

Lake Powell		
Elevation (feet)	**Operation According to the Interim Guidelines**	**Live Storage (maf)[1]**
3,700	**Equalization Tier** Equalize, avoid spills, or release 8.23 maf	24.3
3,636-3,666 (2008-2026)	**Upper Elevation Balancing Tier[3]** Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	**15.5-19.3** (2008-2026)
3,575	**Mid-Elevation Release Tier** Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	9.5
3,525		5.9
3,490	**Lower Elevation Balancing Tier** Balance contents with a min/max release of 7.0 and 9.5 maf	4.0
3,370		0

+

Lower Basin Delivery Concept

Lake Mead		
Elevation (feet)	**Operation According to the Interim Guidelines**	**Live Storage (maf)[1]**
1,220	**Flood Control Surplus or Quantified Surplus Condition** Deliver > 7.5 maf	25.9
1,200 (approx.)[2]	**Domestic Surplus or ICS Surplus Condition** Deliver > 7.5 maf	22.9 (approx.)[2]
1,145	**Normal or ICS Surplus Condition** Deliver ≥ 7.5 maf	15.9
1,075	**Shortage Condition** Deliver 7.167[4] maf	9.4
1,050	**Shortage Condition** Deliver 7.083[5] maf	7.5
1,025		5.8
1,000	**Shortage Condition** Deliver 7.0[6] maf Further measures may be undertaken[7]	4.3
895		0

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Current Paradigm

Concepts

Used to define Lake Powell releases & Lower Basin deliveries—based on criteria, configuration, and release modifications

Lake Powell Release Concept

Lake Powell Release Concept

Criteria: Not applicable

Configuration: Tiered

Release Modification: Balancing

Lake Powell		
Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
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895		0

Lower Basin Delivery Concept

Criteria: Mead Pool Elevation

Configuration: Tiered

Delivery Modification: None

Levers

User-defined values that complete the definition of an operational strategy

Number of Lake Powell operating tiers

Elevation thresholds to define each tier

Annual (WY) release volumes

Minimum and maximum balancing release volumes

Reference elevations

Lake Powell Release Concept

Lake Powell		
Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
3,700	**Equalization Tier** Equalize, avoid spills, or release 8.23 maf (1)	24.3
3,636-3,666 (2008-2026)	**Upper Elevation Balancing Tier[3]** Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf (2)	15.5-19.3 (2008-2026)
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Lower Basin Delivery Concept

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1,025		5.8
1,000	**Shortage Condition** Deliver 7.0[6] maf. Further measures may be undertaken[7] (6)	4.3
895		0

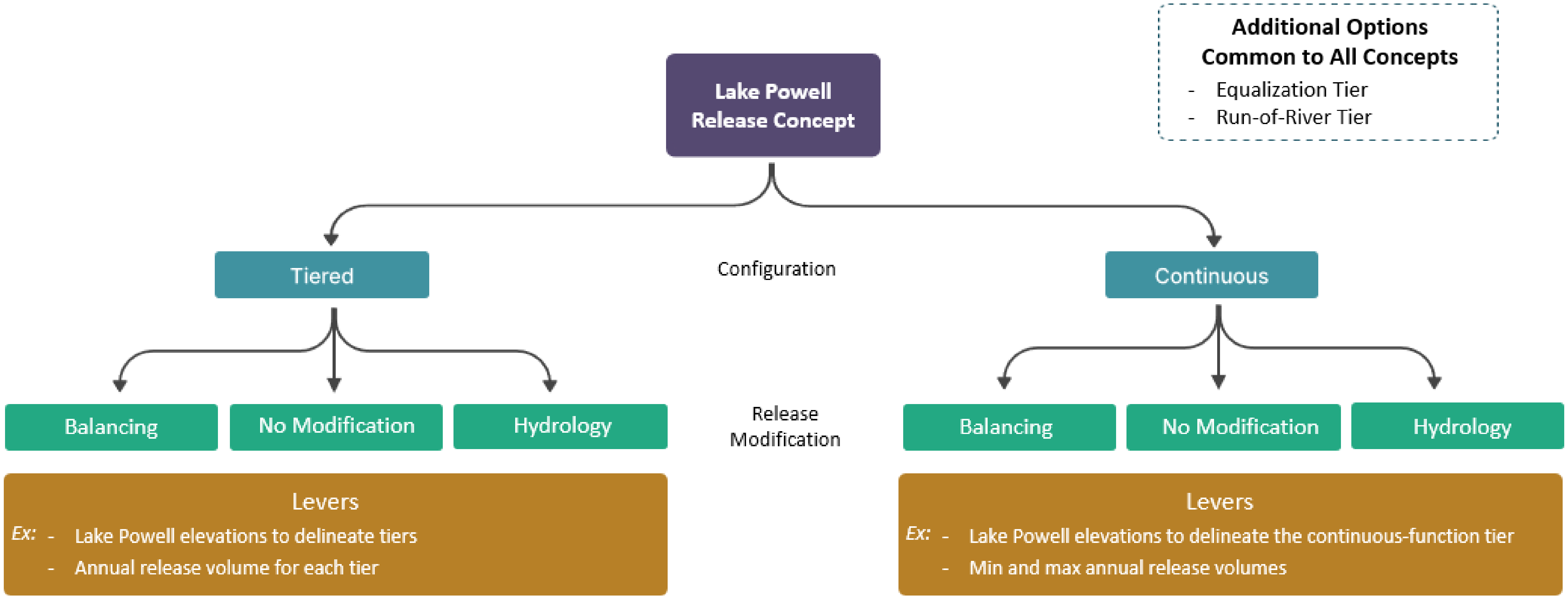
Number of Lake Mead operating tiers

Elevation thresholds to define each tier

Annual (CY) Lower Basin delivery volumes

Lake Powell Release Concepts

Overview of Lake Powell Release Concepts



Visualizing Lake Powell Release Concepts

2007 IG Visualization

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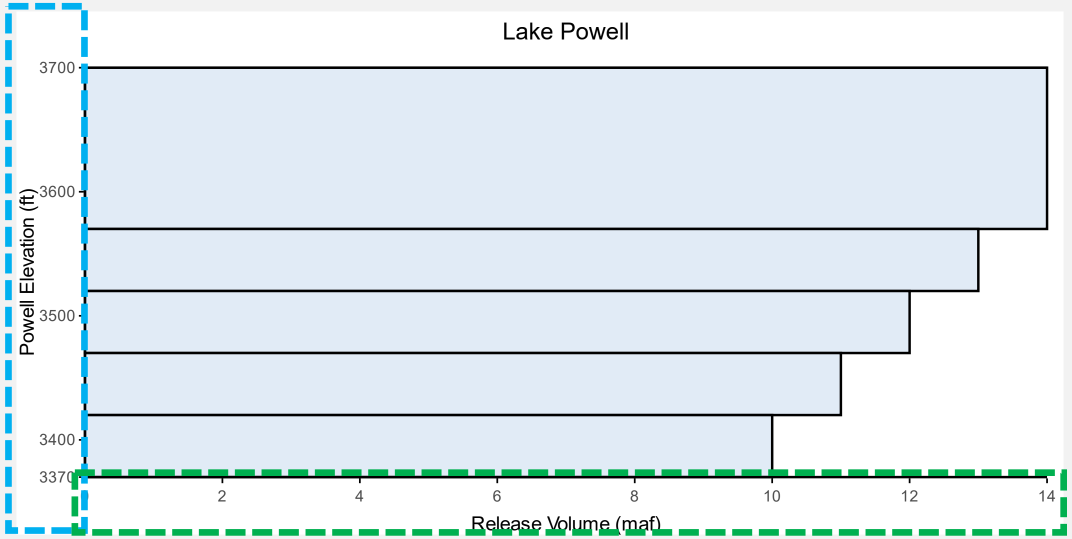
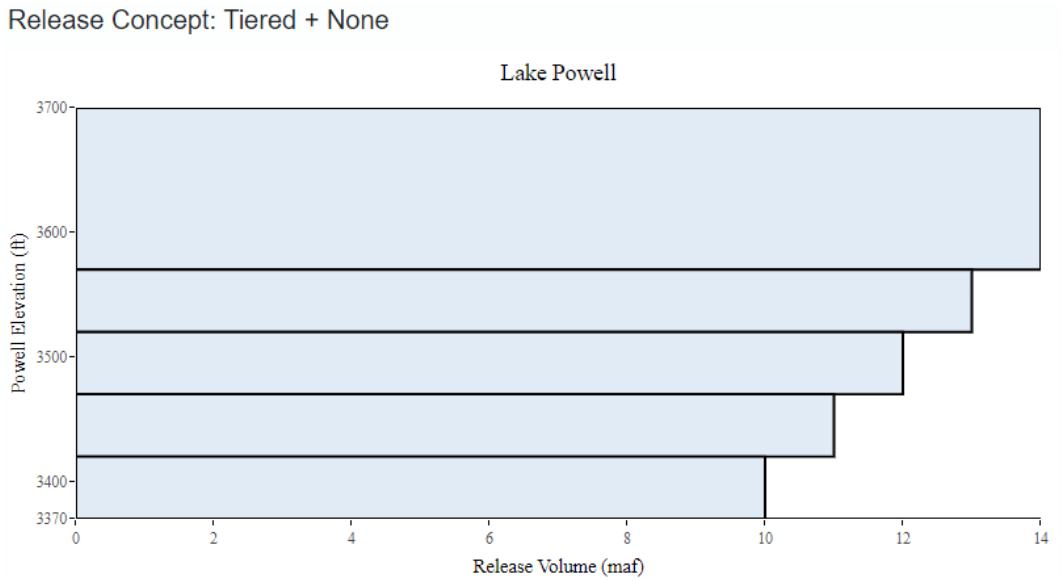
Web Tool Visualization



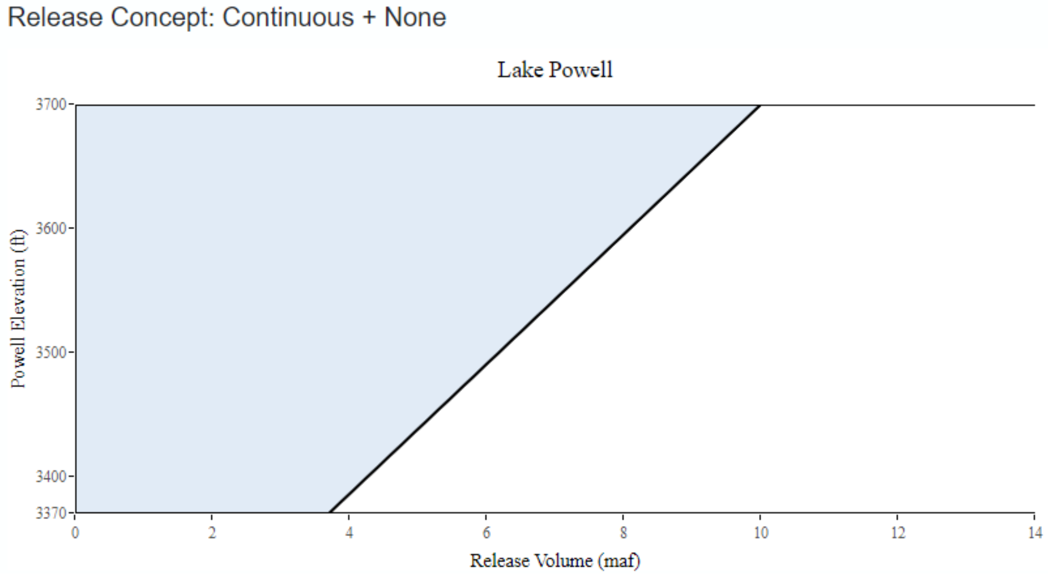
Tiered +
No Modification

Lake Powell Release Configurations

Tiered + No Modification



Continuous + No Modification



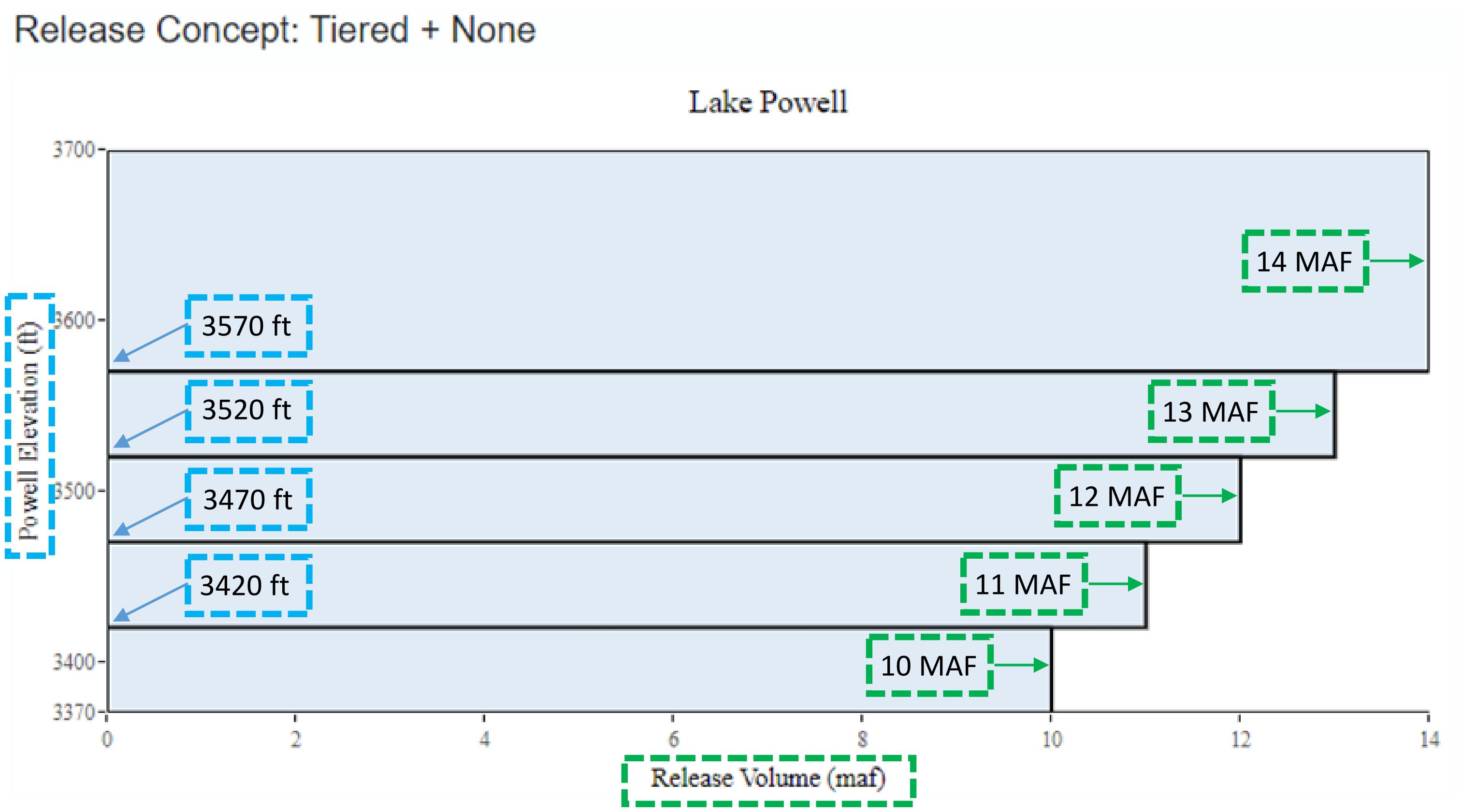
Lake Powell Release Concept
Tiered + No Modification

Configuration

- Annual (WY) release volumes are based on **discrete bands** defined by Lake Powell pool elevations
- Up to 5 user-defined tiers

Levers

- Elevation thresholds used to define tiers
- Annual (WY) release volume associated with each tier



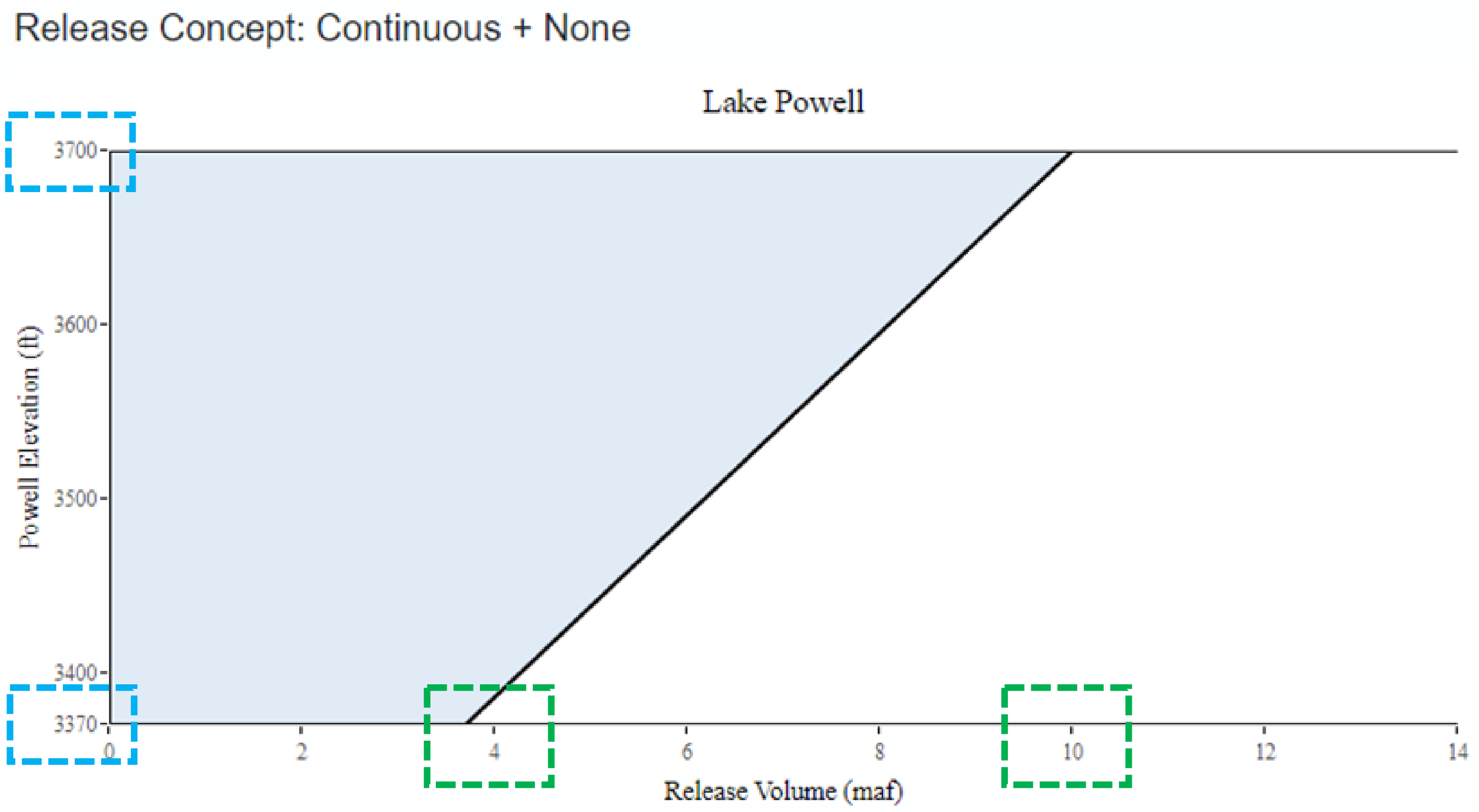
Lake Powell Release Concept
Continuous + No Modification

Configuration

- Annual (WY) release volumes are determined using a **continuous function** of Lake Powell pool elevations

Levers

- Bound the continuous function
- Top and bottom pool elevations
- Max and min annual release volume



Release Modification
Balancing

- Annual release volumes can be modified at the beginning of the year or adjusted mid-year if Lake Mead's pool elevation falls below specified thresholds
- The objective of balancing is to achieve a balanced distribution of storage between the two reservoirs by the end-of-water-year
  - Equally balancing the contents may not be possible depending on the exact lever values of an operational strategy and the relative reservoir levels
- Implementation of balancing is different in the tiered and continuous configurations

Release Modification
Balancing

Lake Powell		
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Release 7.0 to 9.0 maf if Mead < 1,075 ft
- Mead reference pool elevation used to trigger balancing
- Min and max **balancing release**

Release 8.23 maf if Mead < 1,025 ft
- Mead reference elevation
- Single alternate release volume

Release 7.0 to 9.5 maf
- Min and max **balancing release**
- **Balance only tier**: balancing release is not triggered by Mead elevation

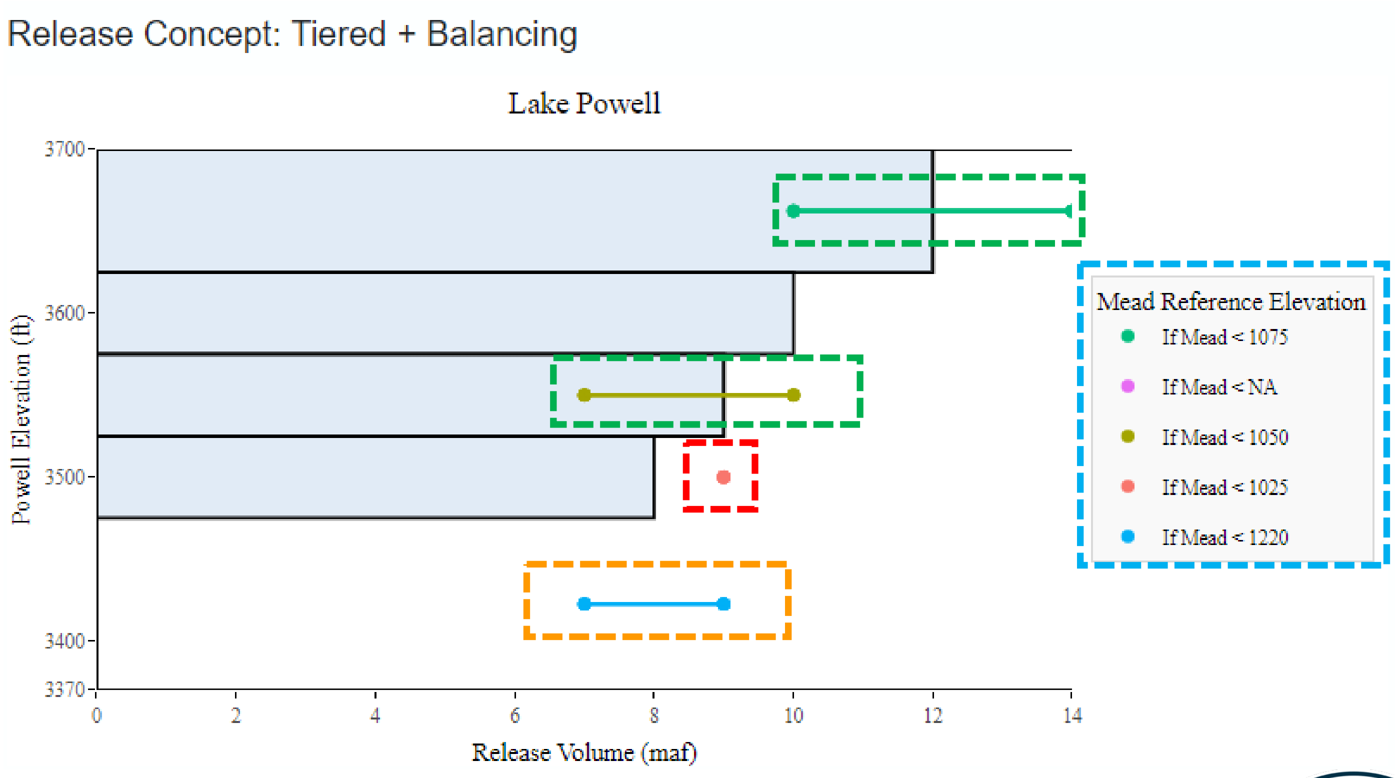
Lake Powell Release Concept
Tiered + Balancing Modification

Modification

- Annual (WY) release volumes can be modified at the beginning of the year or adjusted if Lake Mead's elevation falls below specified thresholds

Levers

- Lake Mead reference elevation
- Modified releases
  - Minimum balancing release
  - Maximum balancing release
  - Alternative release volume
- Balancing only operations (optional) with min & max balancing release



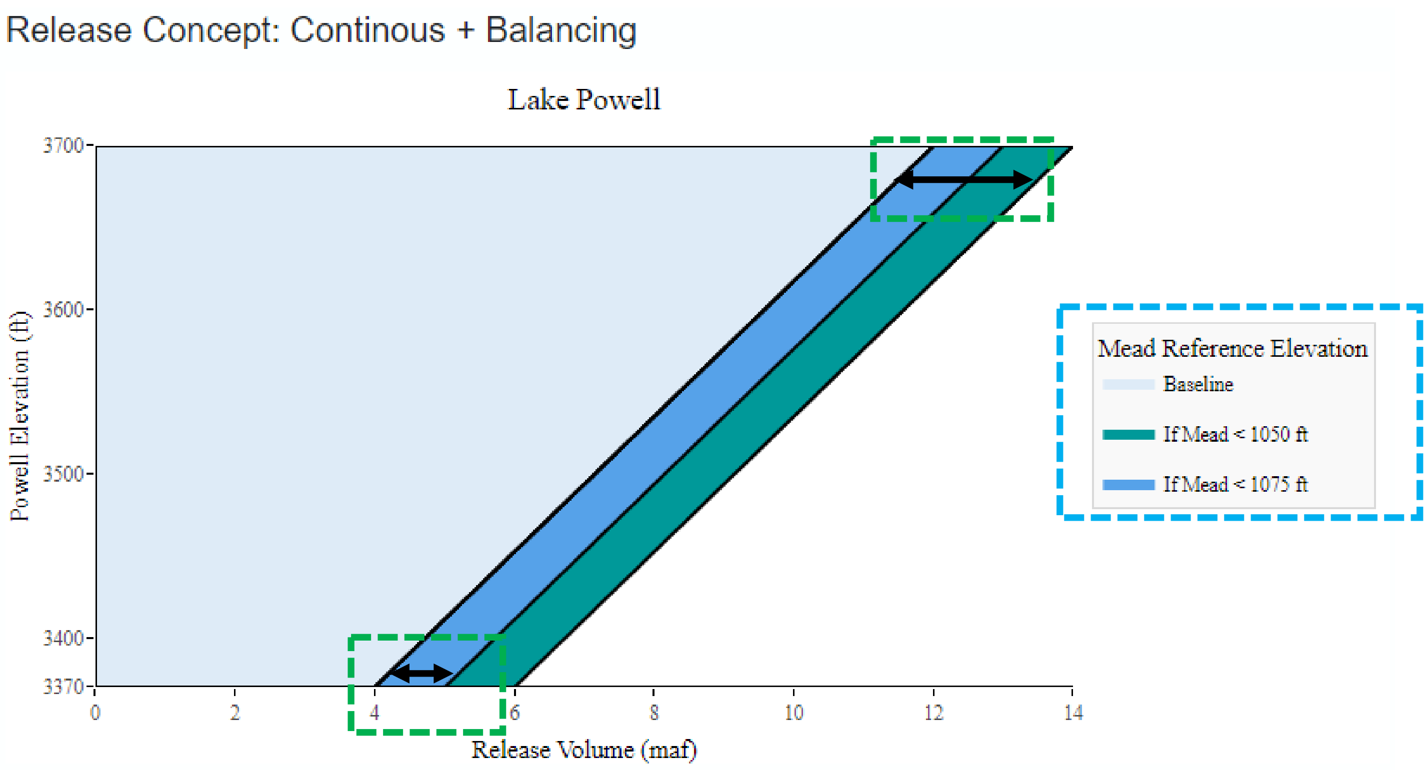
Lake Powell Release Concept
Continuous + Balancing Modification

Modification

- Annual (WY) release volume is adjusted based on Lake Mead pool elevation
- Up to two balancing modifications

Levers

- Lake Mead reference elevation
- Maximum release volume increase (offset from primary release volume "line)



Release Modification
Hydrology

- Annual release volumes can be reduced at the beginning of the year if recent hydrology falls below specified thresholds
- This modification enables Lake Powell releases to adapt to recent hydrologic conditions
- Implementation of the hydrology modification is similar in tiered and continuous configurations
    - Based on running average of Lees Ferry natural flow
- Can NOT be combined with Balancing modification

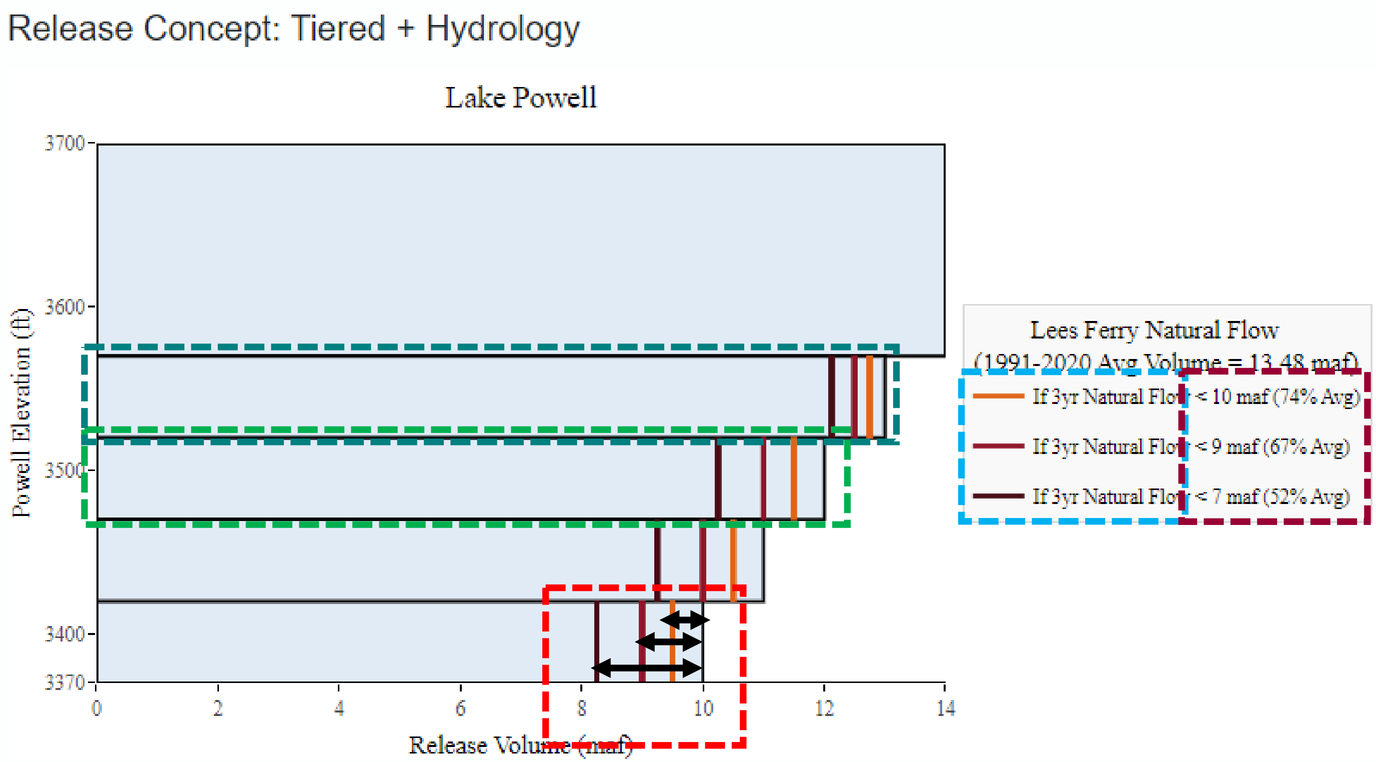
Lake Powell Release Concept
Tiered + Hydrology Modification

Modification

- Annual (WY) release volumes can be modified at the beginning of the year if recent hydrology falls below specified thresholds

Levers

- Number of previous years (3 or 5) used to calculate the running average for Lees Ferry natural flow
- Flow thresholds used to trigger modification (max 4)
- First tier in which the modification is implemented (i.e., starting tier)
- Volume used to reduce the annual release (i.e., reduction volume)
- *Optional:* Phase-in (on or off)
    - If on, 50% of the reduction volume is applied to the annual release in the tier above the starting tier



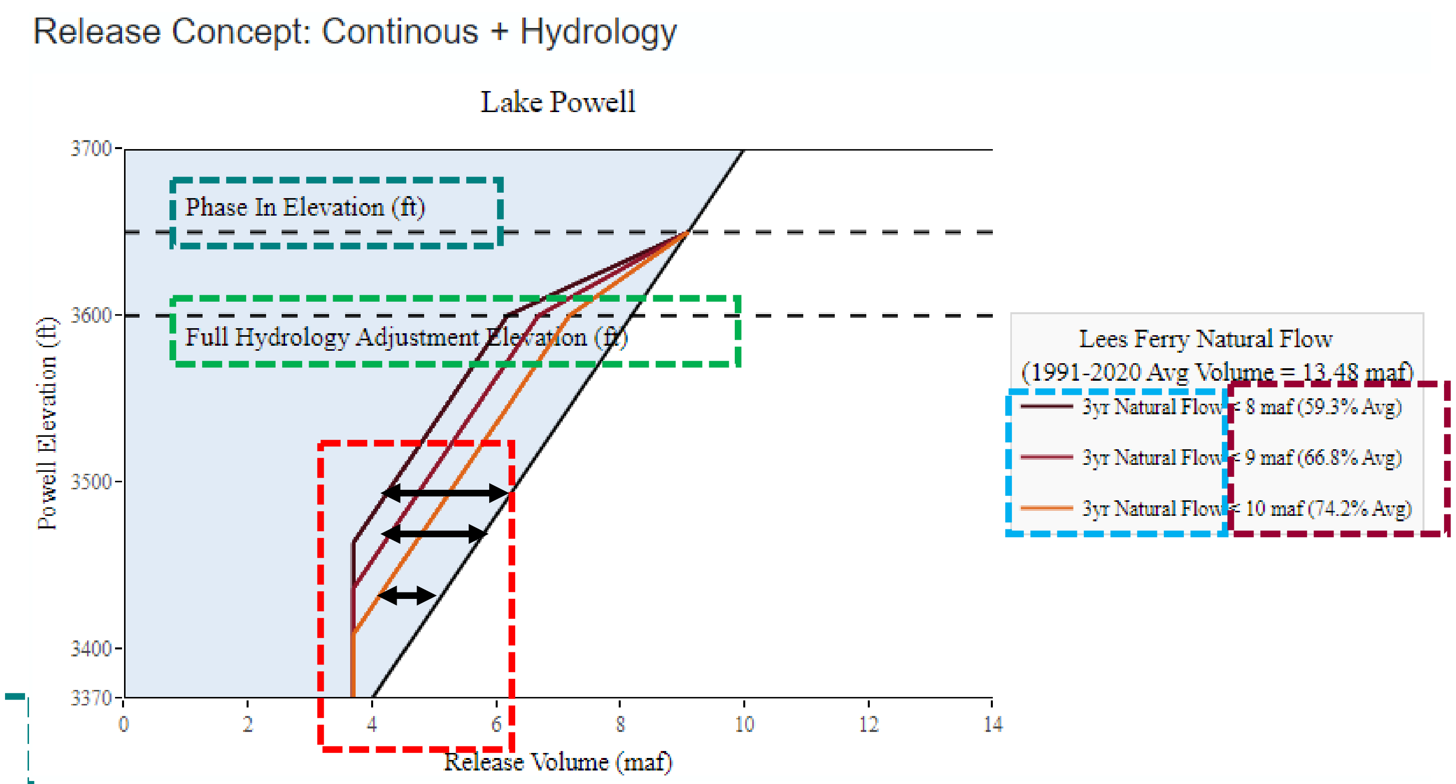
Lake Powell Release Concept
Continuous + Hydrology Modification

Modification

- Annual volumes can be modified at the beginning of the year if recent hydrology falls below specified thresholds

Levers

- Flow record for average (3 or 5-year running average)
- Flow thresholds that trigger modification (up to 4)
- Starting elevation at which full release modification takes effect
- Volume of release reduction
- *Optional:* Phase-in (on or off)
  - If on, Pool Elevation in which the Hydrology Modification will begin to phase-in. The phase-in volume starts at zero and increases linearly until it reaches the full Hydrology Modification



Lake Powell Release Concept – Additional Options
Equalization Tier

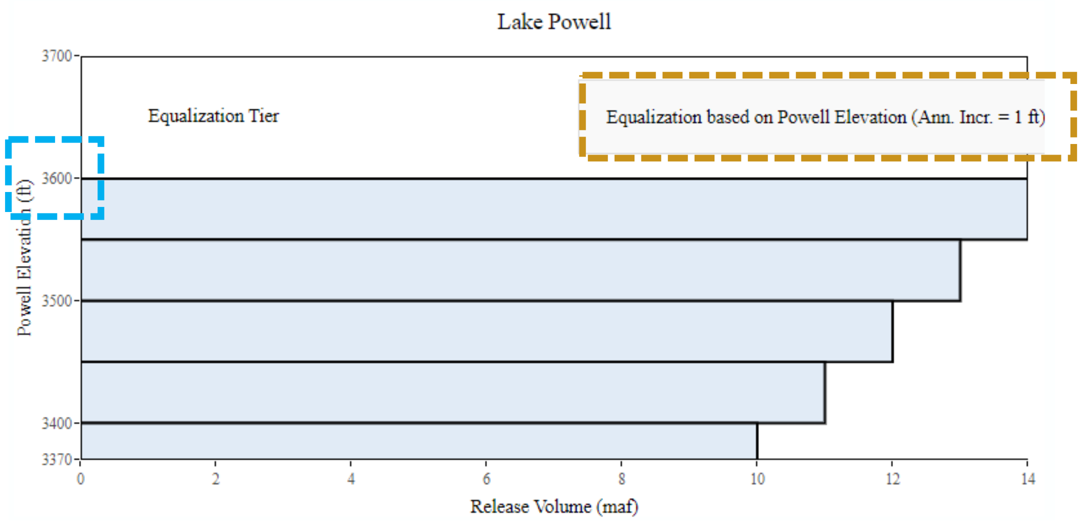
Overview

- The objective of equalization is to achieve a balanced distribution of storage between the two reservoirs by the end of the water year
- Equalization is triggered when:
  - The equalization threshold is crossed
  - The forecasted end-of-water year storage is greater in Lake Powell than in Lake Mead
- Equalization threshold can be defined two ways

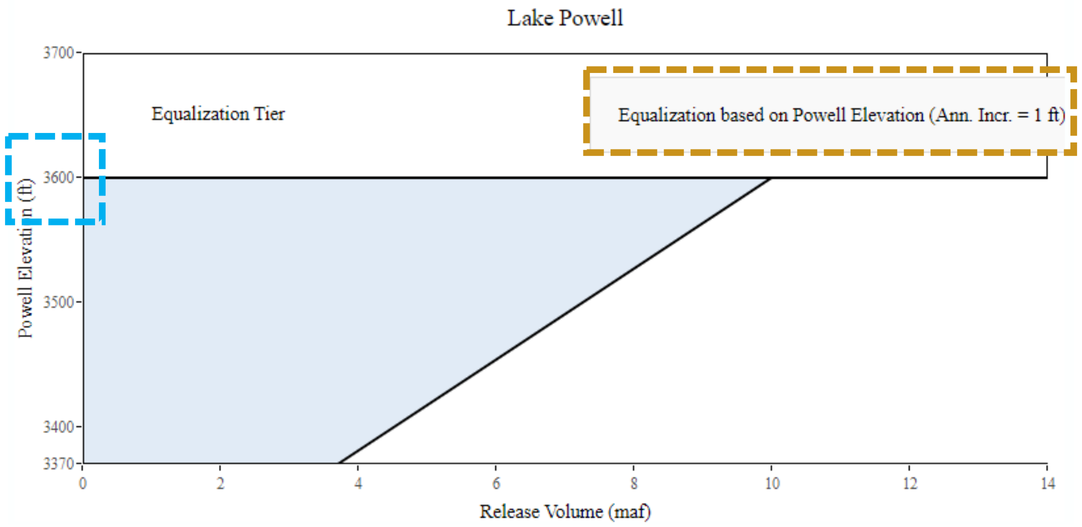
Levers

- Lake Powell elevation OR Colorado River Storage Project (CRSP) reservoirs' percent-full
- EQ threshold increase

Release Concept: Tiered + None

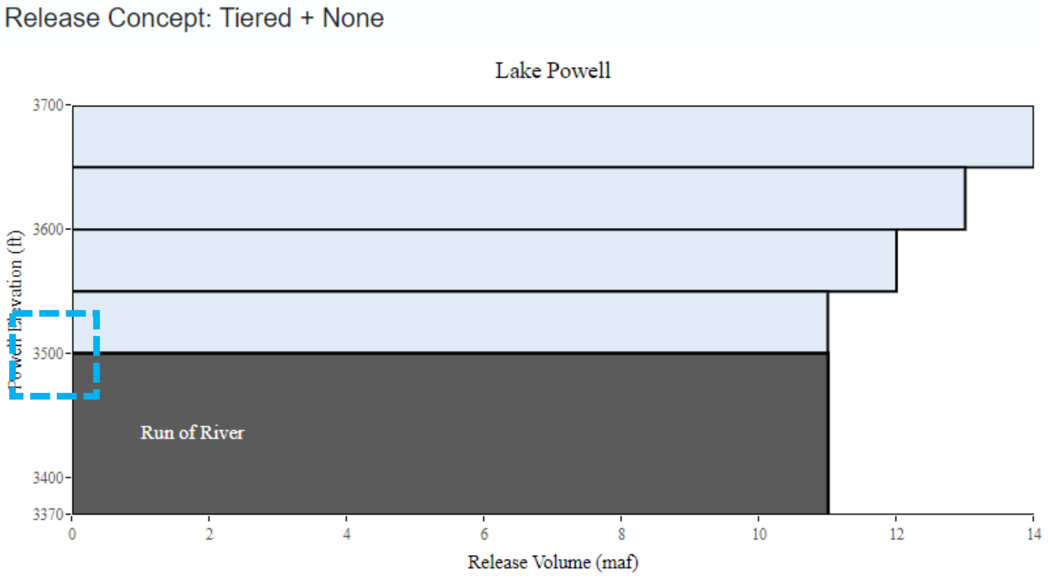


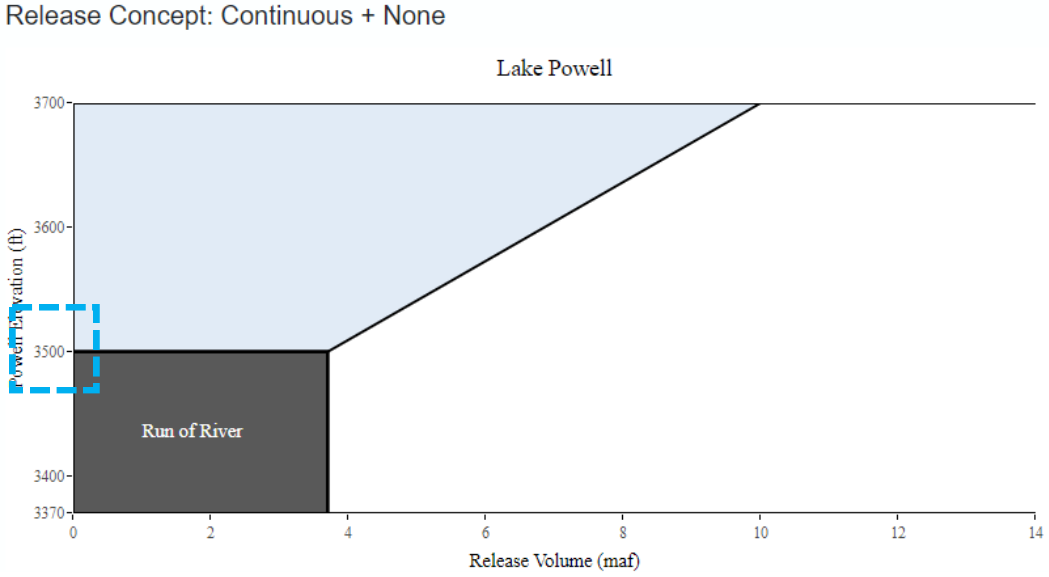
Release Concept: Continuous + None



Lake Powell Release Concept – Additional Options

Run-of-River Tier





Overview

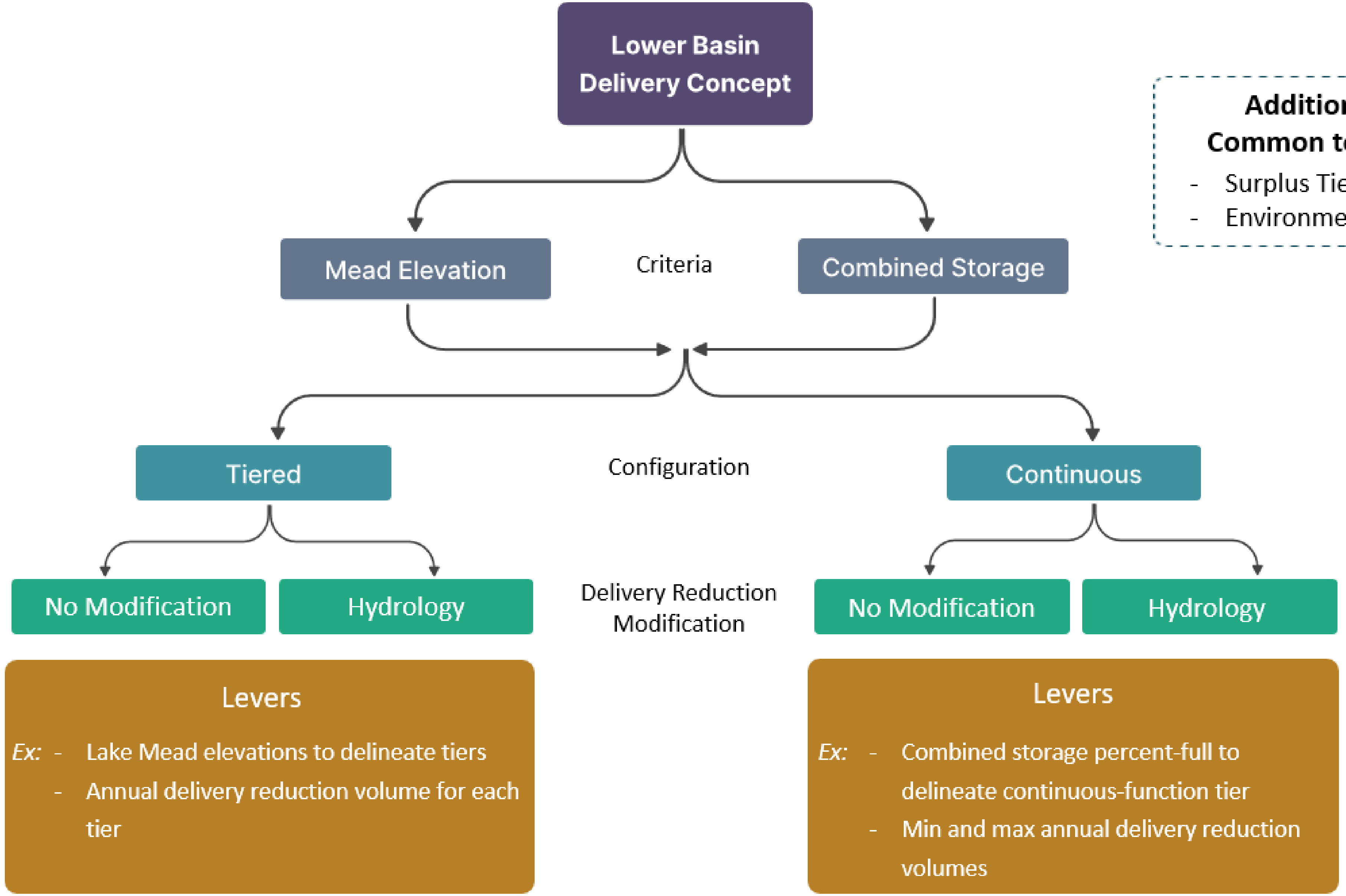
- Always bottom tier, bound by a starting elevation
- Outflow = inflow, unless inflow is greater than minimum release in tier above

Levers

- Starting elevation (below continuous tier or lowest tier in Tiered)

Lower Basin Delivery Concepts

Overview of Lower Basin Delivery Concepts



Additional Options Common to All Concepts

- Surplus Tier
- Environmental Flows

Visualizing Lower Basin Delivery Concepts

2007 IG Visualization

Lake Mead		
Elevation (feet)	Operation According to the Interim Guidelines	Live Storage (maf)[1]
1,220	**Flood Control Surplus or Quantified Surplus Condition** Deliver > 7.5 maf	25.9
1,200 (approx.)[2]	**Domestic Surplus or ICS Surplus Condition** Deliver > 7.5 maf	22.9 (approx.)[2]
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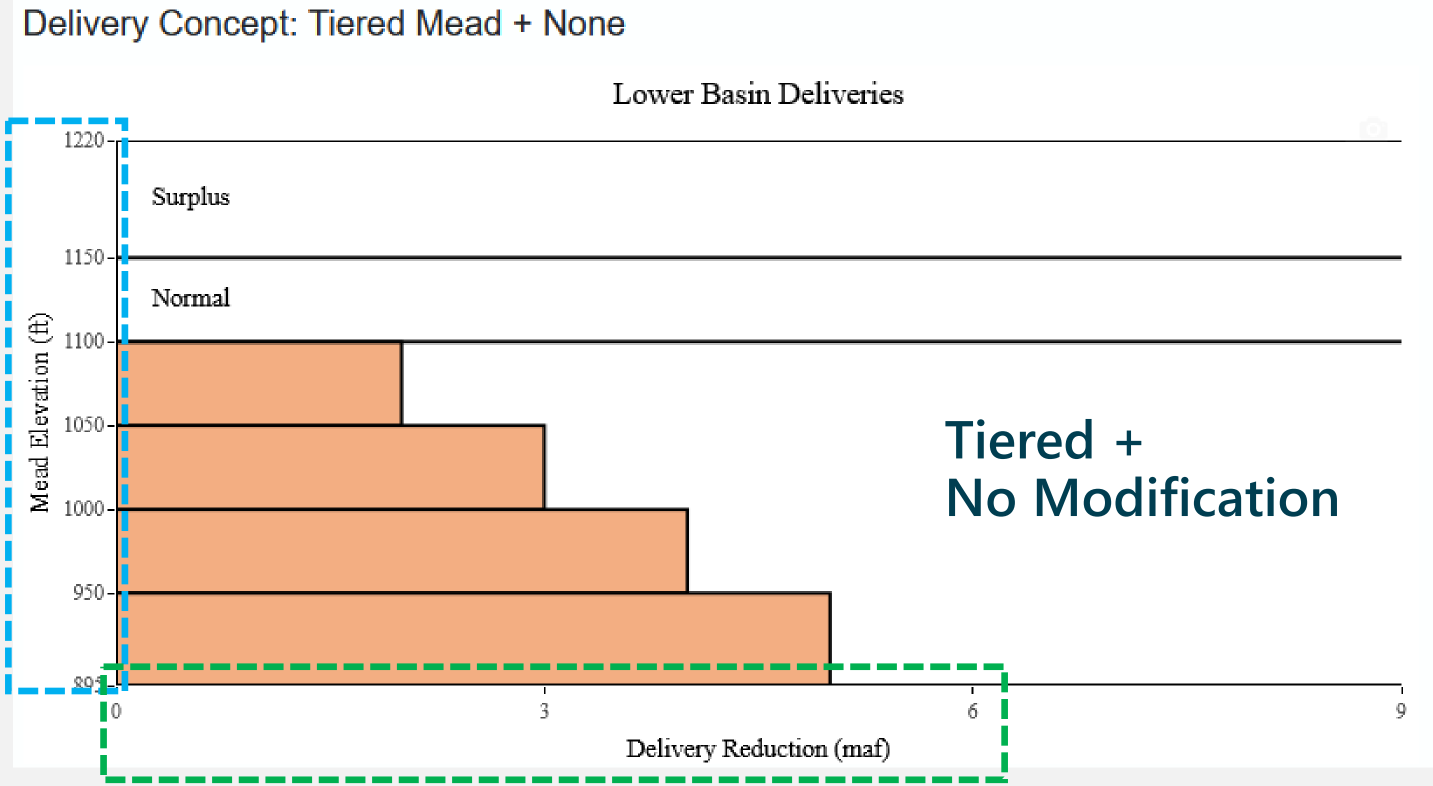
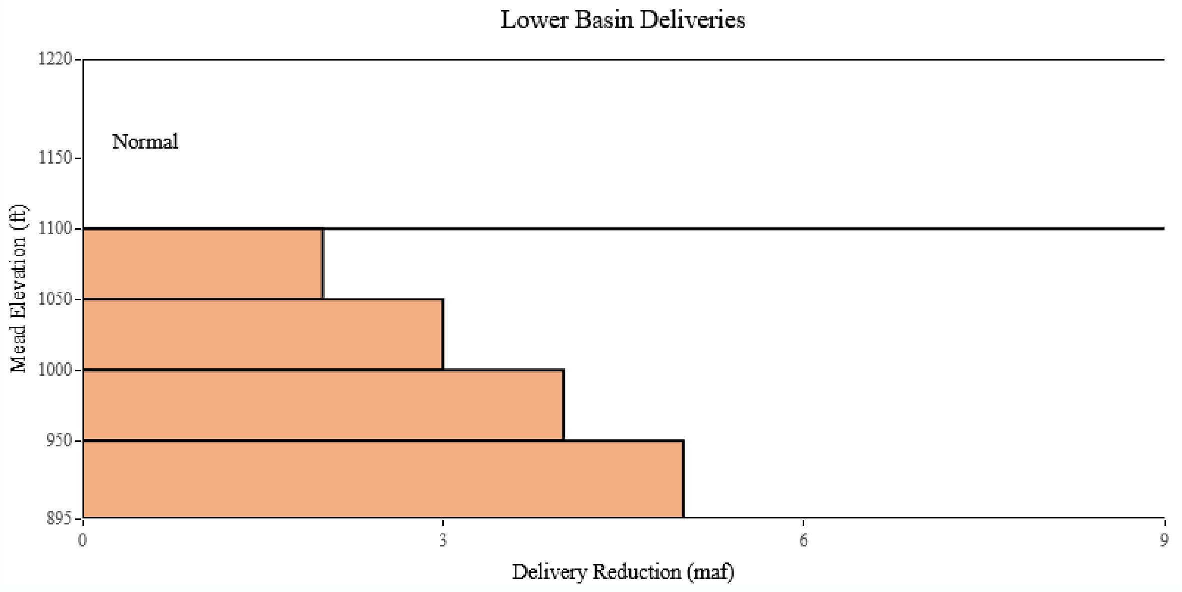
Web Tool Visualization



Lower Basin Delivery Configurations

Tiered + No Modification

Delivery Concept: Tiered Mead + None



Continuous + No Modification

Delivery Concept: Continuous Mead + None

Lower Basin Delivery Concept
Tiered + No Modification

Criteria

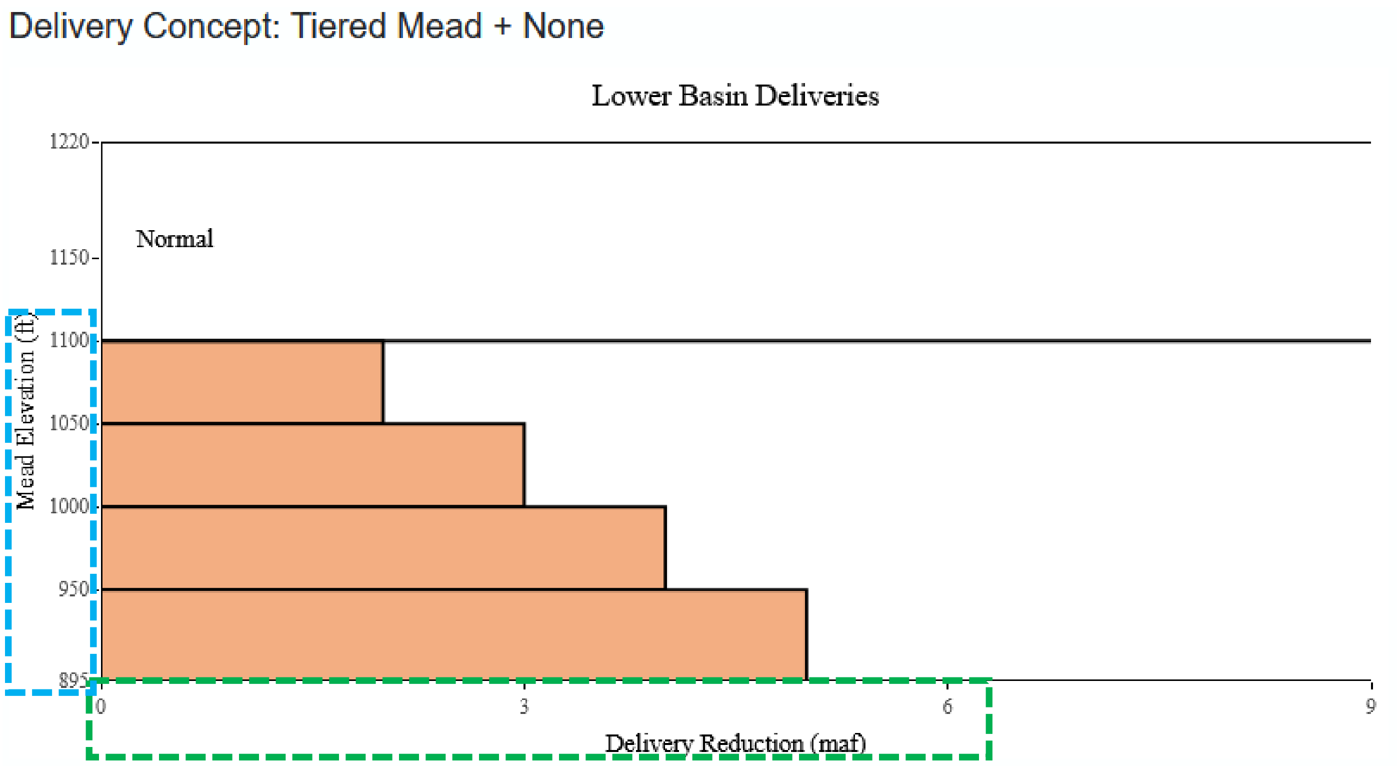
- Lake Mead pool elevation

Configuration

- Annual (CY) Lower Basin delivery volumes are based on **discrete bands** defined by Lake Mead pool elevations
- Up to 8 user-defined tiers

Levers

- Elevation thresholds used to define tiers
- Annual (CY) delivery reduction volume associated with each tier



**Delivery reductions are not assigned to any one state or water user and are modeled as total Lower Basin use reduction.*

Lower Basin Delivery Concept
Continuous + No Modification

<u>Criteria</u>

- Lake Mead pool elevation

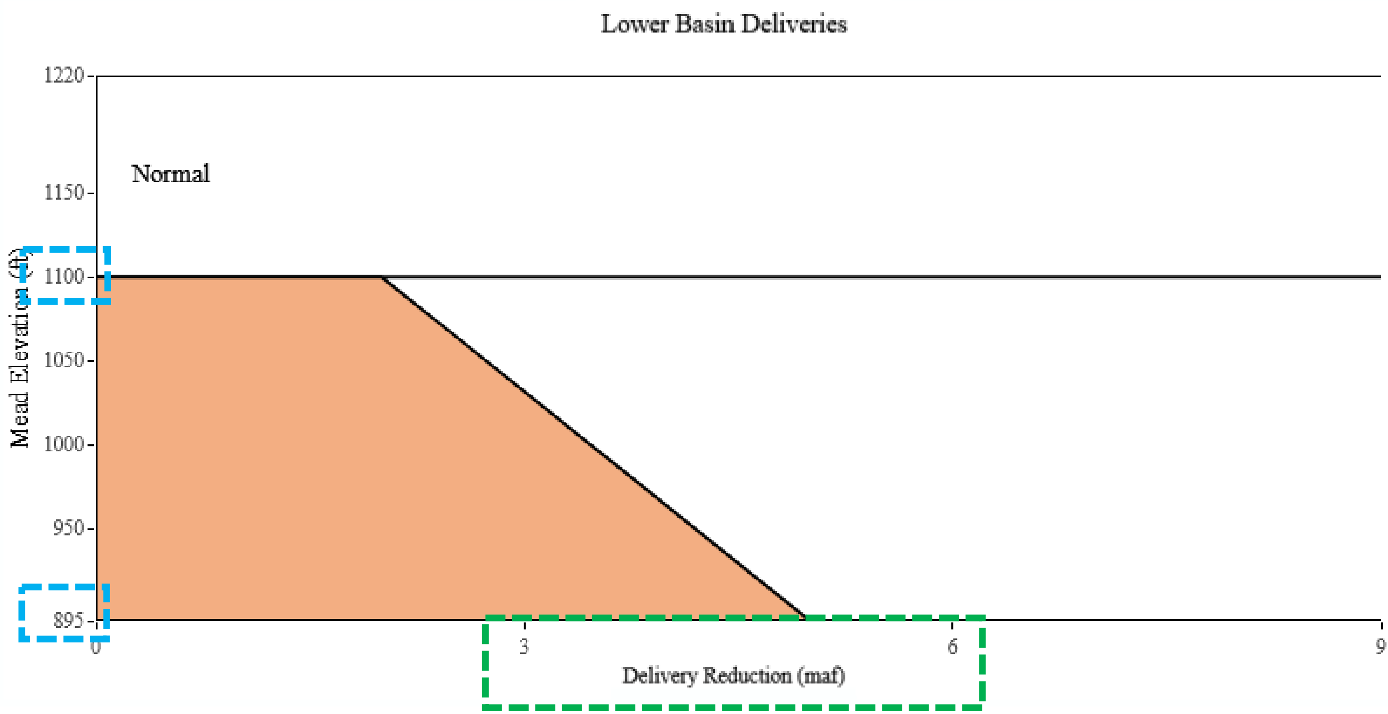
<u>Configuration</u>

- Annual (CY) Lower Basin delivery volumes are based on a **continuous function** of Lake Mead pool elevation (or combined storage percent full)

<u>Levers</u>

- Lake Mead pool elevations used to delineate top and bottom of continuous function
- Maximum and minimum annual delivery reduction volumes for continuous-function reduction tier

Delivery Concept: Continuous Mead + None



**Delivery reductions are not assigned to any one state or water user and are modeled as total Lower Basin use reduction.*

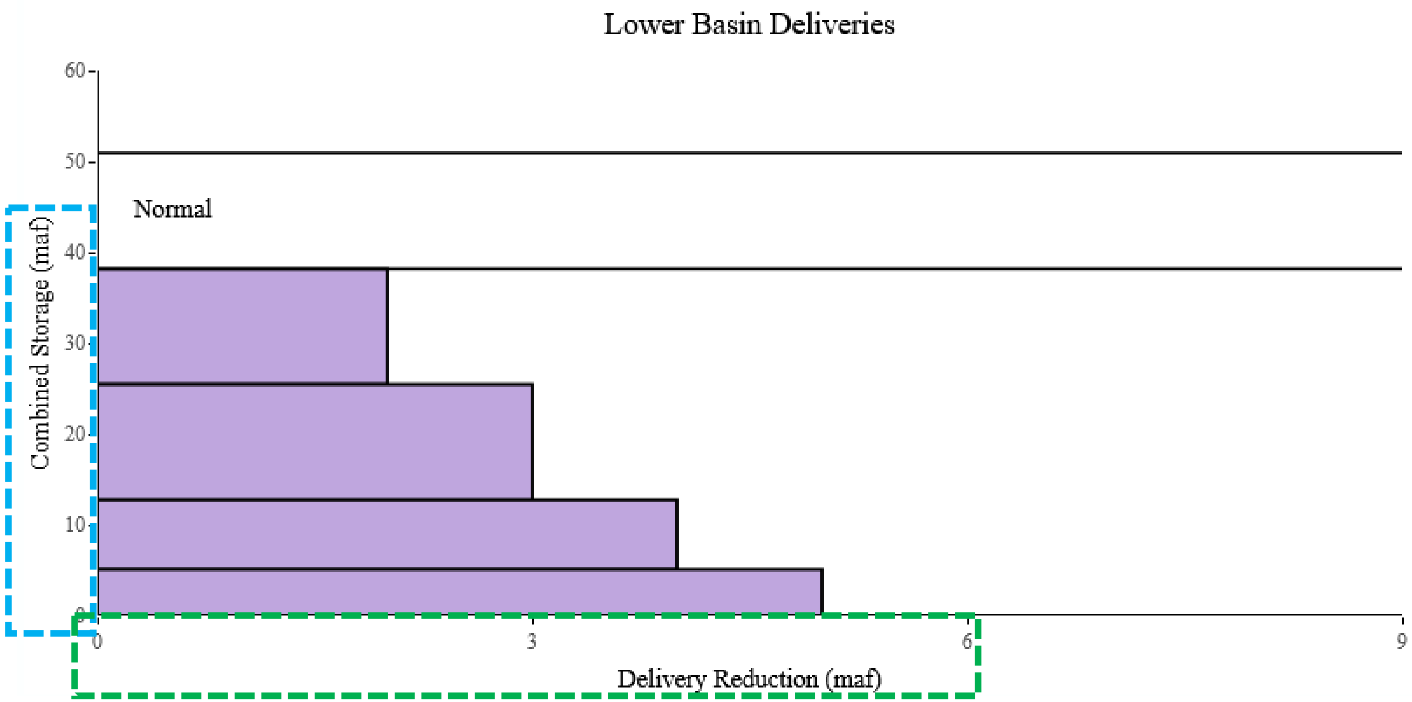
Lower Basin Delivery Concept
Tiered + No Modification

Criteria
- Combined storage

Configuration
- Annual (CY) Lower Basin delivery volumes are based on discrete bands defined by combined storage (% full)
- Up to 8 user-defined tiers

Levers
- Combined storage thresholds used to define tiers
- Annual (CY) delivery reduction volume associated with each tier

Delivery Concept: Tiered Combined Storage + None



**Delivery reductions are not assigned to any one state or water user and are modeled as total Lower Basin use reduction.*

Delivery Modification
Hydrology

- Annual Lower Basin delivery reduction volumes can be increased at the beginning of the year if recent hydrology falls below specified thresholds
- This modification enables Lower Basin delivery reductions to adapt to recent hydrologic conditions
- Implementation of the hydrology modification is similar in tiered and continuous configurations
  - Based on running average of Lees Ferry natural flow

Lower Basin Delivery Concept
Tiered + Hydrology Modification

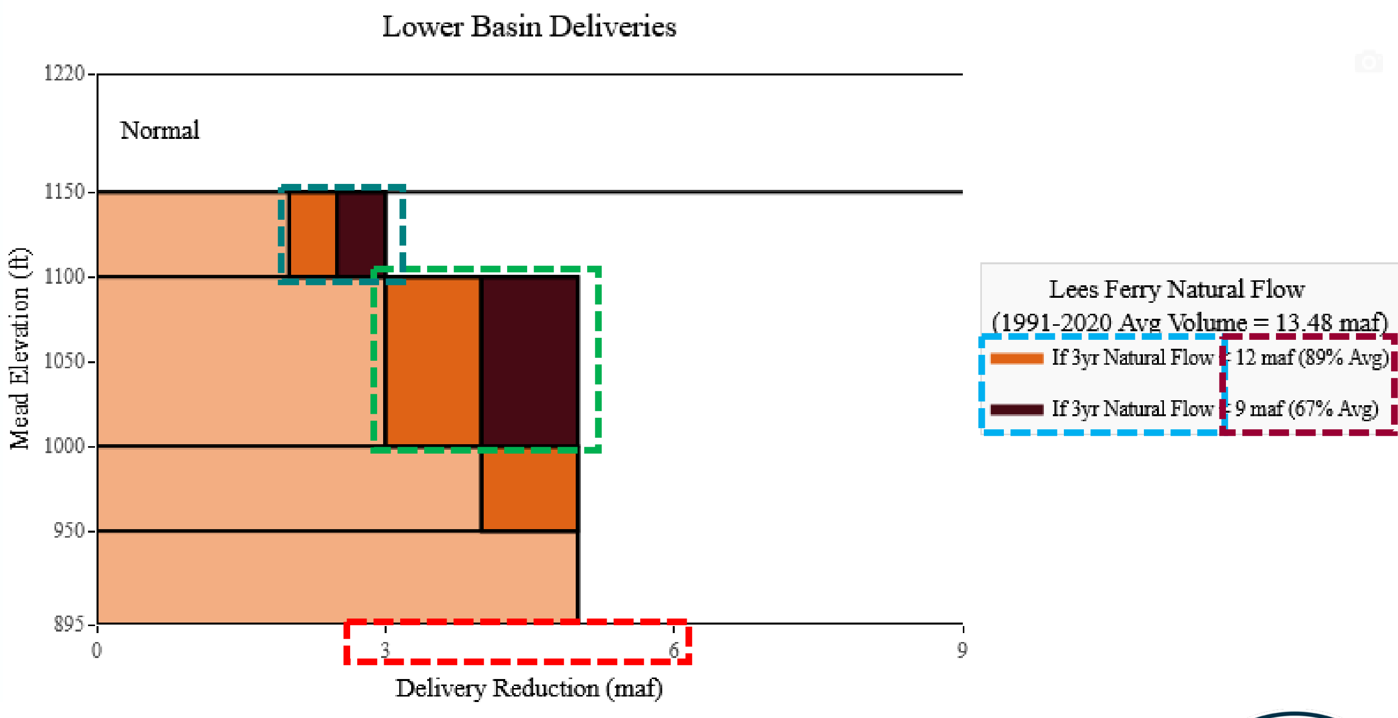
Modification

- Annual (CY) delivery reduction volumes can be modified at the beginning of the year if recent hydrology falls below specified thresholds

Levers

- Number of previous years used to calculate the running average (3 or 5) for Lees Ferry natural flow
- Flow threshold used to trigger modification (max 4)
- First tier in which the modification is implemented (i.e., starting tier)
- Additional delivery reduction volume
- *Optional:* Phase-in (on or off)
    - If on, 50% of the additional delivery reduction is applied to the annual delivery reduction in the tier above the starting tier

Delivery Concept: Tiered Mead + Hydrology



**Delivery reductions are not assigned to any one state or water user and are modeled as total Lower Basin use reduction.*

Lower Basin Delivery Concept
Continuous + Hydrology Modification

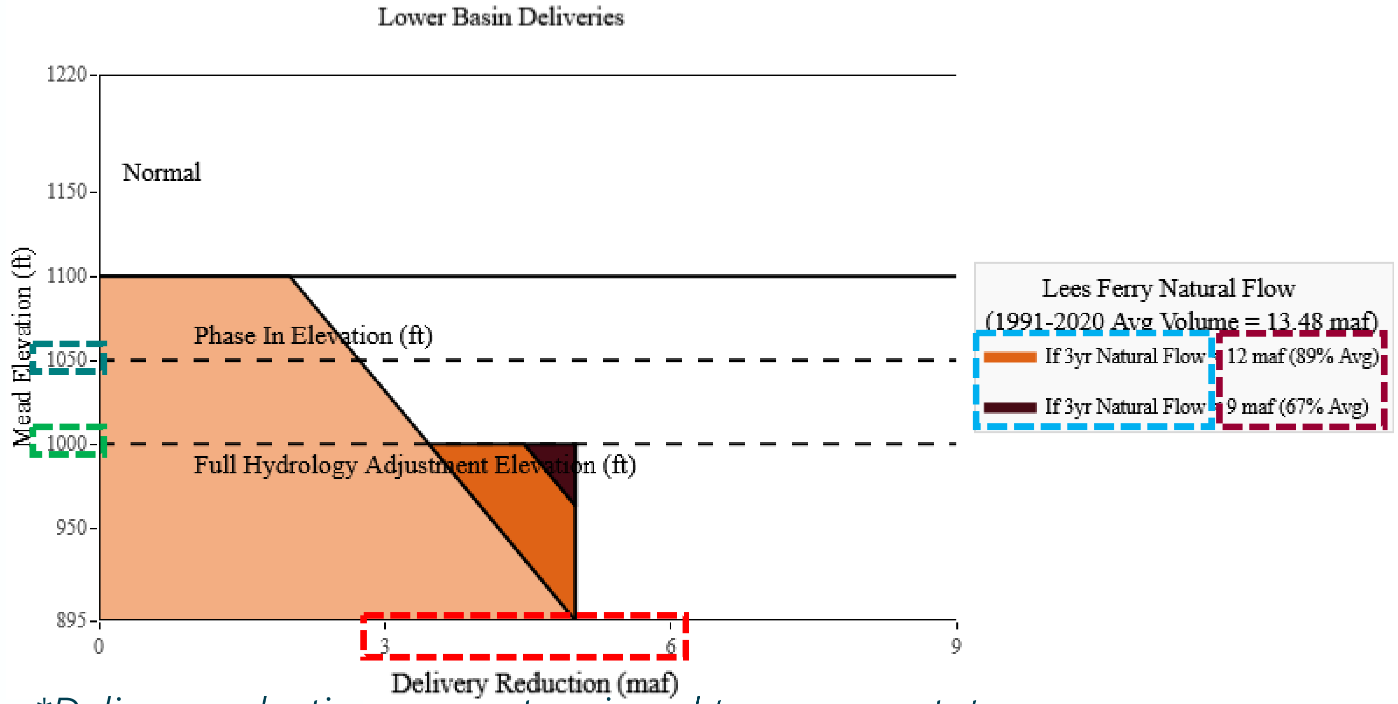
Modification

- Annual delivery reduction volumes can be modified at the beginning of the year if recent hydrology falls below specified thresholds

Levers

- Number of previous years used to calculate the running average (3 or 5) for Lees Ferry natural flow
- Flow threshold used to trigger modification (max 4)
- Elevation threshold below which the modification is implemented
- Additional delivery reduction volume
- *Optional:* Phase-in (on or off)
  - If on, additional delivery reduction begins at specified elevation threshold, gradually increasing until it achieves full hydrology modification delivery reduction volume at the start of the hydrology modification

Delivery Concept: Continuous Mead + Hydrology



**Delivery reductions are not assigned to any one state or water user and are modeled as total Lower Basin use reduction.*

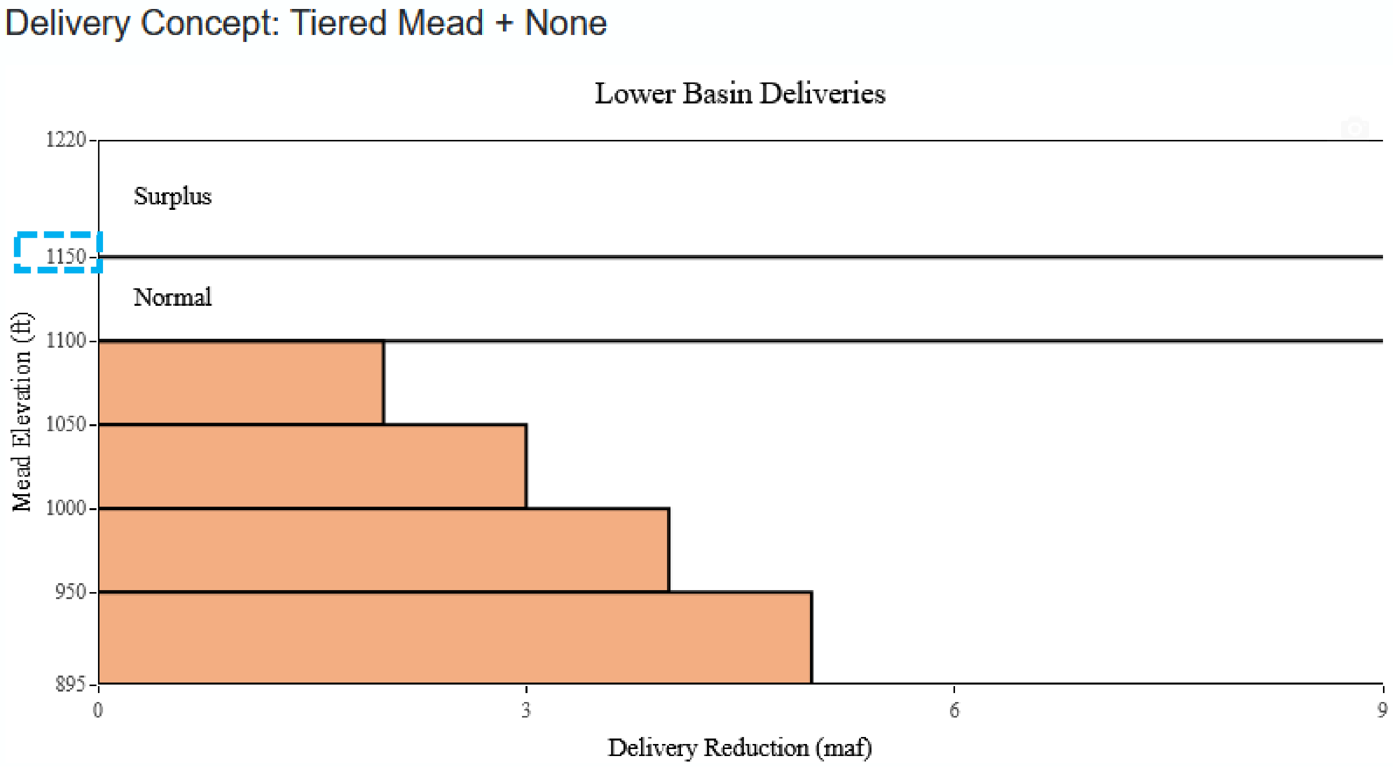
Lower Basin Delivery Concepts — Additional Options
Surplus Tier

Overview

Annual surplus delivery of 450 kaf made to Lower Basin water users when Lake Mead is above a specified elevation (pool elevation criteria) or percentage of combined storage (combined storage criteria)

Levers

- Turn surplus on (off is default)
- Select the surplus start pool elevation/combined storage percent



**Surplus deliveries are not assigned to any one state or water user and are modeled as a total Lower Basin delivery increase.*

Lower Basin Delivery Concepts — Additional Options

Combined Storage Definition

Overview: Combined Storage, a criteria used to trigger Lower Basin delivery reductions, can be defined four different ways by including different combinations of Upper and Lower Basin reservoirs

Levers: Select the reservoirs used to define Combined Storage

- Include Lake Powell + Lake Mead (default; always included)
- Add CRSP Reservoirs (Flaming Gorge, Blue Mesa, Navajo)
- Add Lake Havasu and Lake Mohave

Environmental Flows

Overview: Environmental flows released from Lake Mead for the Colorado River Delta. Releases made if water is available in Lake Mead in a given year, irrespective of delivery reductions.

Levers:

- Environmental flow volume, ranging from 10 kaf – 2 maf
- Environmental flow frequency, occurring every 1-5 years

Summary of Web Tool Concepts & Paradigms

- Lake Powell and Lake Mead operations can be configured in many ways—including paradigms that are very different from current operations
- 6 Lake Powell Release Concepts

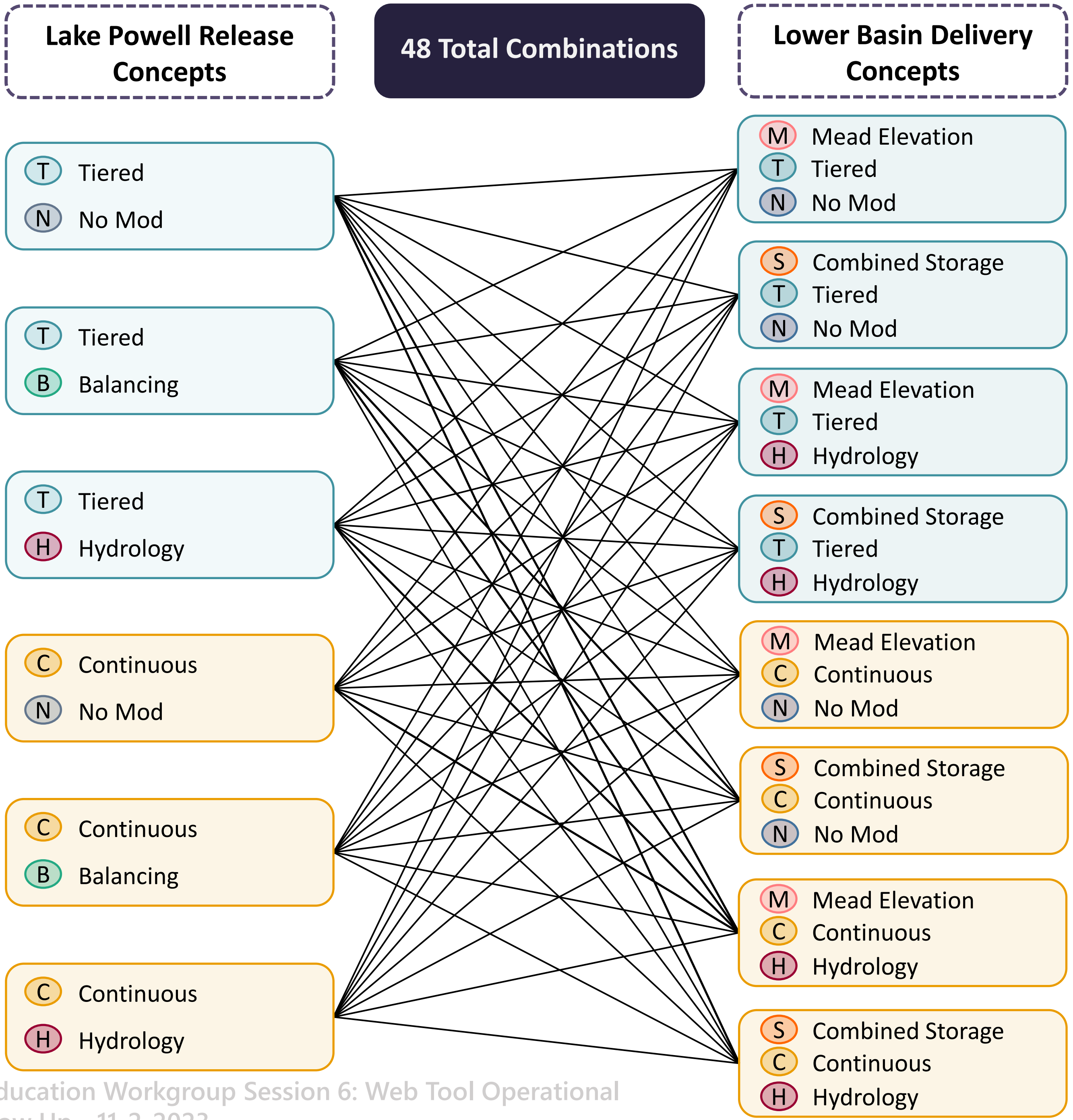
Tiered	Continuous
No Modification	No Modification
Hydrology Modification	Hydrology Modification
Balancing Modification	Balancing Modification

- 8 Lower Basin Delivery Concepts

Tiered	Continuous
Defined using Mead Elevation	Defined using Mead Elevation
Defined using Mead Elevation + Hydrology Modification	Defined using Mead Elevation + Hydrology Modification
Defined using Combined Storage	Defined using Combined Storage
Defined using Combined Storage + Hydrology Modification	Defined using Combined Storage + Hydrology Modification

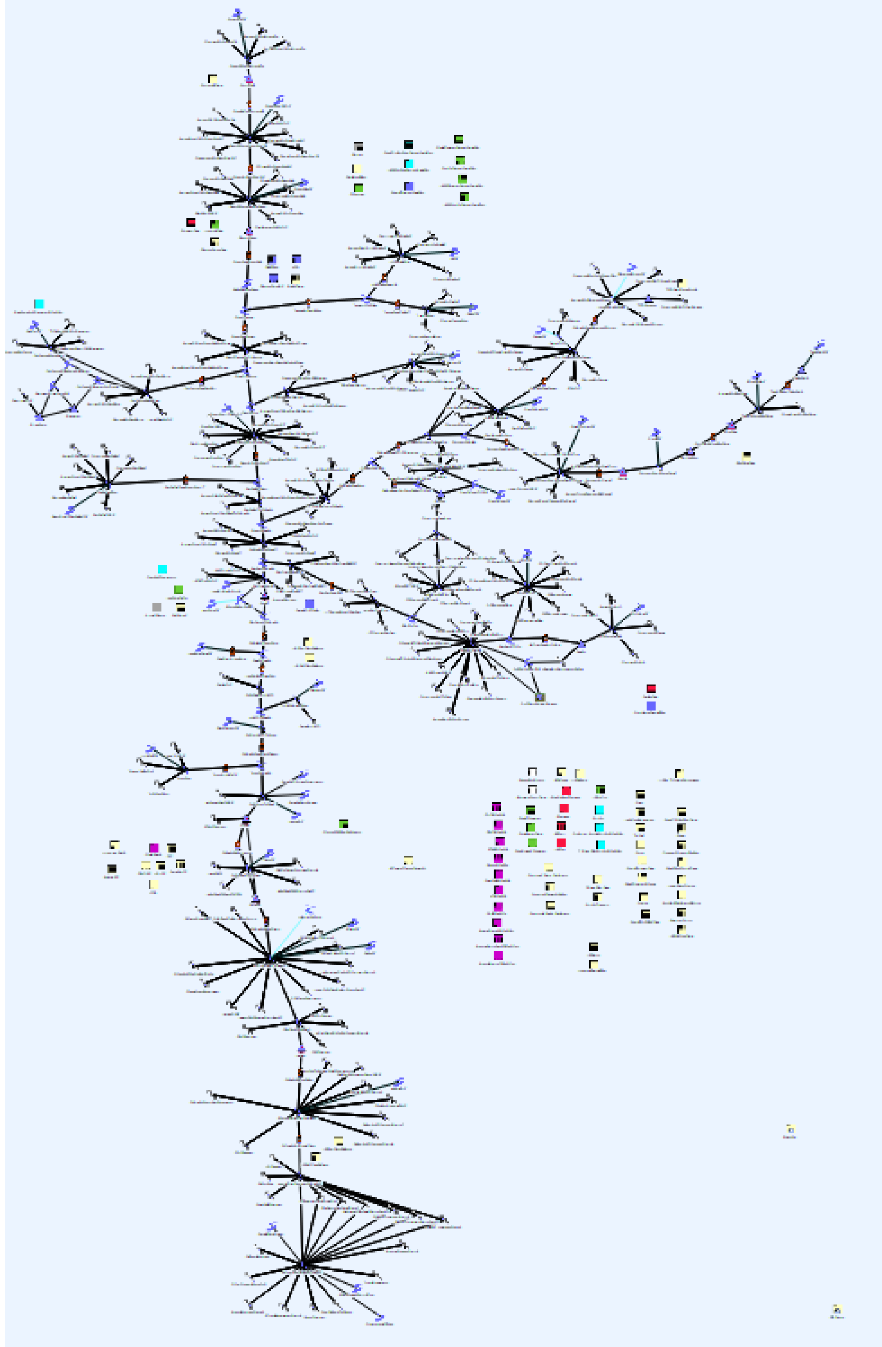
- Results in 48 paradigms

Lake Powell Release Concept + **Lower Basin Delivery Concept** = **Paradigm**


Lake Powell Release Concepts
48 Total Combinations
Lower Basin Delivery Concepts
T Tiered
N No Mod
T Tiered
B Balancing
T Tiered
H Hydrology
C Continuous
N No Mod
C Continuous
B Balancing
C Continuous
H Hydrology
M Mead Elevation
T Tiered
N No Mod
S Combined Storage
T Tiered
N No Mod
M Mead Elevation
T Tiered
H Hydrology
S Combined Storage
T Tiered
H Hydrology
M Mead Elevation
C Continuous
N No Mod
S Combined Storage
C Continuous
N No Mod
M Mead Elevation
C Continuous
H Hydrology
S Combined Storage
C Continuous
H Hydrology

Web Tool Model Development

- Requires highly flexible and robust models
- Created 4 paradigm models using v6 of Reclamation's Colorado River Simulation System (CRSS) RiverWare model
    - Tiered Powell Releases + Tiered Lower Basin Delivery
    - Tiered Powell Releases + Continuous-Function Lower Basin Delivery
    - Continuous-Function Powell Releases + Continuous-Function Lower Basin Delivery
    - Continuous-Function Powell Releases + Tiered Lower Basin Delivery
- 1 ruleset per model
- Value of each lever is set using customized input file structure
- Includes ability to easily select the desired criteria, configuration, modifications and additional options



Summary of Enhanced Model Flexibility

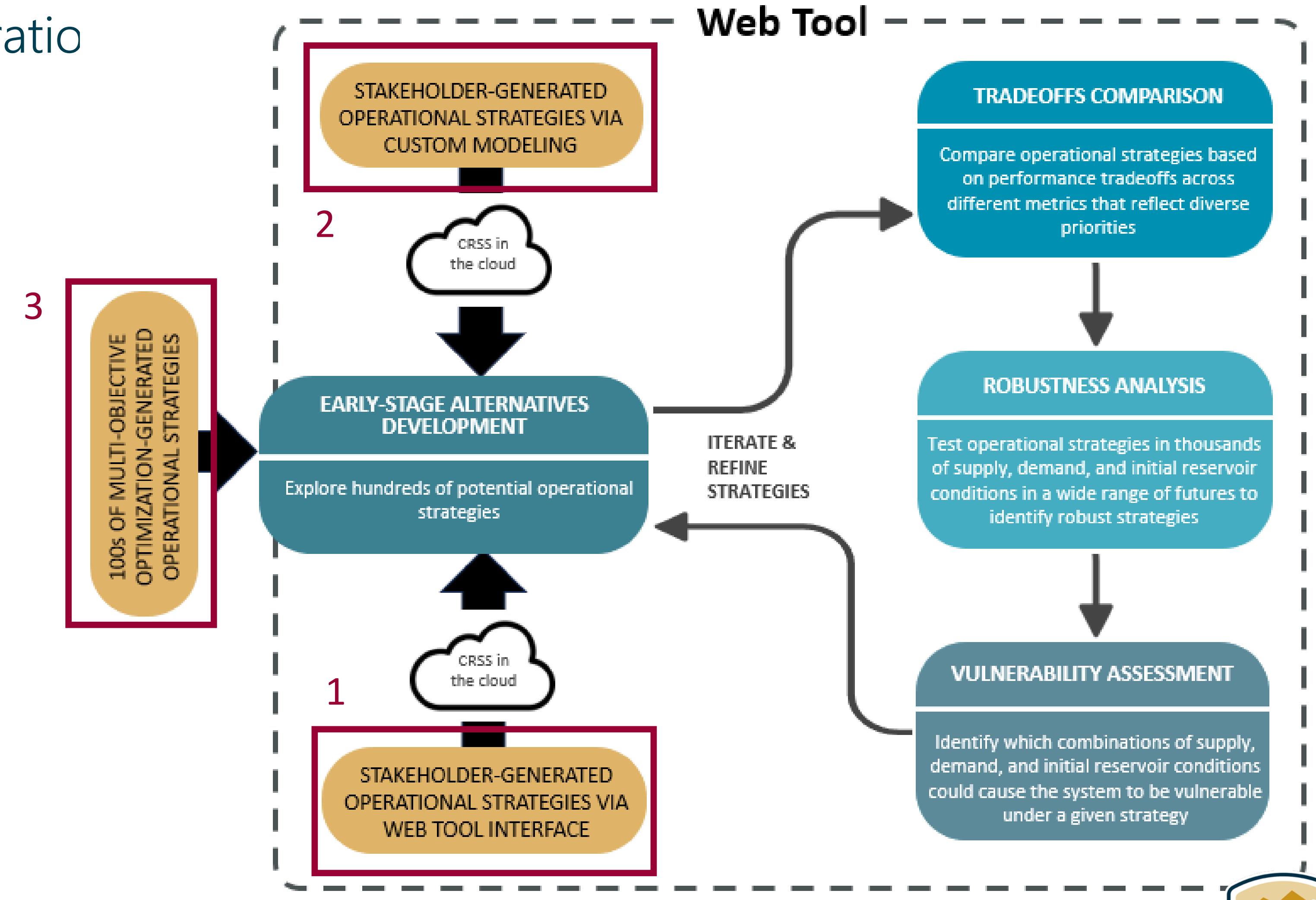
Each model includes enhanced flexibility with respect to

- Number of Powell release tiers
- Number of Lower Basin Delivery tiers
- Criteria (Combined Storage or Lake Mead Pool Elevation) used define the Lower Basin Delivery tiers
- Thresholds used to define the operating tiers
- Powell release and Lower Basin delivery reduction volumes
- Balancing by tier (on/off) and reference elevation
- Equalization, including how the equalization threshold is defined (Lake Powell pool elevation or Total CRSP reservoir storage)
- Incremental or static Equalization line
- Number and volume of hydrology modifications
- Phase-in (on/off) hydrology modifications
- Number of years used to average the flow threshold used in the hydrology modification
- Run-of-river
- User-specified (volume and frequency) environmental flow delivered to the Delta
- Surplus

Operational Strategies in the Post-2026 Web Tool

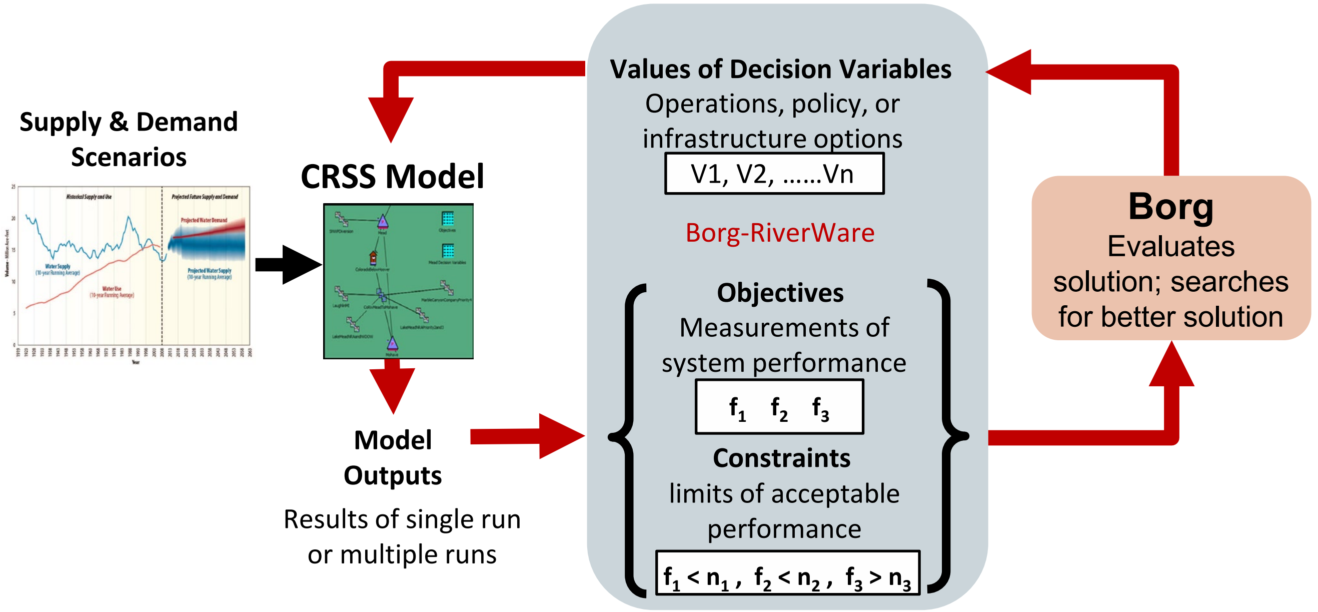
Web Tool features 3 sources of operatio strategies:

1. Stakeholder generated strategies via **web interface** based on the 48 <u>customizable</u> paradigms
2. Stakeholder generated strategies via **custom modeling**
   - Coordinate with Reclamation to prepare model and custom output
3. Multi-objective **optimization**-generated strategies
   - Reclamation approach to populating the Web Tool with diverse strategies for context and ideas



Using Multi Objective Optimization to Generate Web Tool Seed Strategies

- Multi Objective Optimization process efficiently "searched" for new strategies and provided context for comparisons (see ITEW #5)
- Simulated ~250k strategies across 10 different paradigms
- Selected ~200 strategies to include in Web Tool as "seed" strategies
  - Pre-loaded and visible in tool on launch
  - Provide context for comparison and basis for new ideas
  - Strategies created by users or through custom modeling will be added to initial set
- <u>Note</u>: seed strategies do not represent Reclamation's positions on good or preferred operational strategies. They were generated by an algorithm for learning purposes only



Paradigms Used to Generate Web Tool Seed Strategies

- Philosophy for choosing 10 paradigms
  - Represent many new ideas
  - Include many different combinations
  - Enable comparisons (what happens when we change only one thing?)
- Inclusion or exclusion of any paradigm does not indicate Reclamation's position on its merit
- Preliminary inter-paradigm comparisons demonstrate that
  - All paradigms cover similar ranges of performance
  - All paradigms demonstrate the same predominant system tradeoffs: overall storage vs. water deliveries, Powell storage vs. Mead storage
- Further analysis is ongoing

T Tiered N No Mod	+	S Combined Storage T Tiered H Hydrology
T Tiered B Balancing	+	M Mead Elevation T Tiered N No Mod
T Tiered B Balancing	+	M Mead Elevation T Tiered H Hydrology
T Tiered B Balancing	+	S Combined Storage T Tiered N No Mod
T Tiered B Balancing	+	S Combined Storage T Tiered H Hydrology
T Tiered H Hydrology	+	M Mead Elevation T Tiered H Hydrology
T Tiered H Hydrology	+	S Combined Storage T Tiered H Hydrology
C Continuous N No Mod	+	S Combined Storage T Tiered H Hydrology
C Continuous H Hydrology	+	M Mead Elevation C Continuous H Hydrology
C Continuous H Hydrology	+	S Combined Storage C Continuous H Hydrology

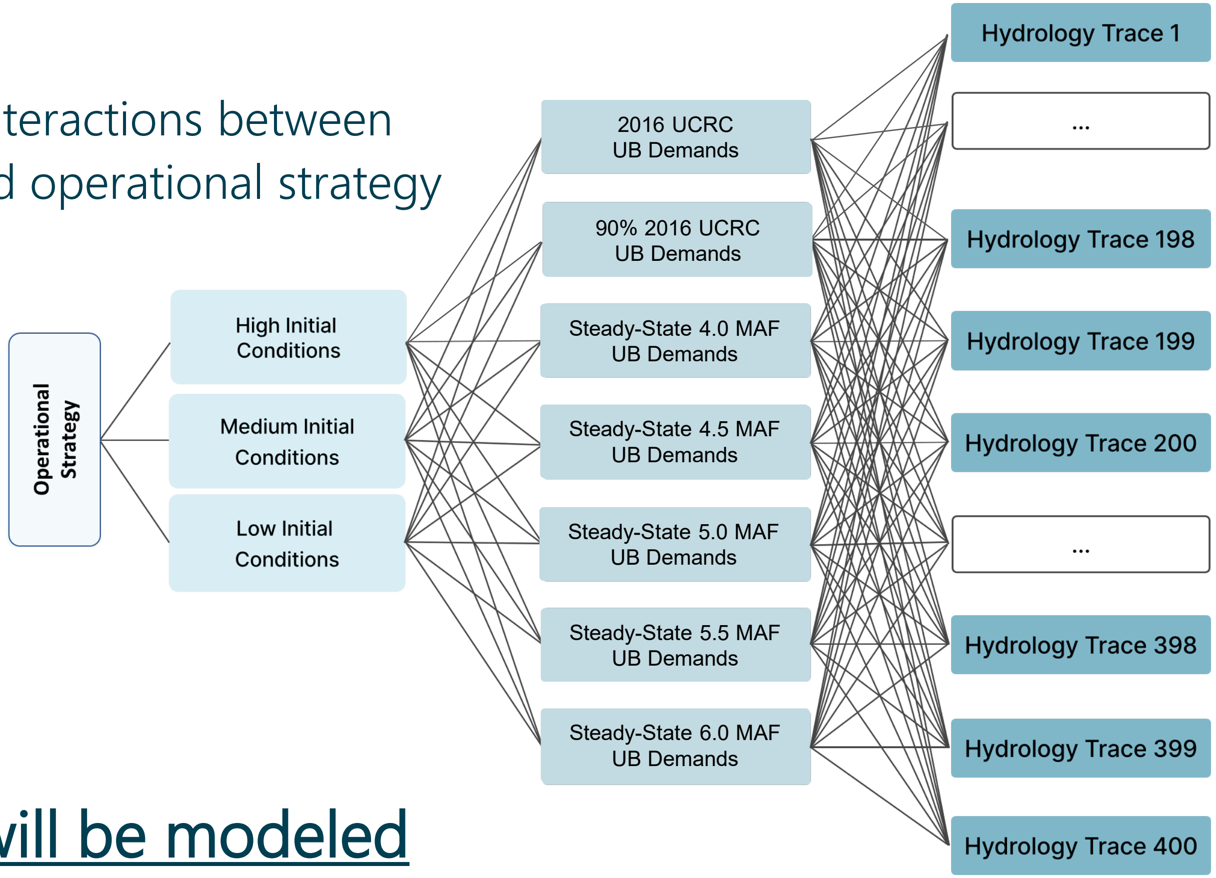
Hydrology, Demands, and Initial Conditions in the Web Tool

Outline

- Uncertainties in the Web Tool
- Hydrology
- Demands
- Initial Conditions
- Vulnerability Analysis Demonstration

Structuring Data to Support DMDU Analysis

- The DMDU analysis in the Post-2026 Web Tool is designed to identify robust operational strategies and learn which future conditions could cause the system to be vulnerable
- Projected system conditions are affected by complex interactions between modeling inputs: supply, demand, initial conditions, and operational strategy
- To generate data that is useful for analyzing vulnerability, we are using 3 sets of initial conditions, 7 UB demand schedules, and 400 hydrology traces as CRSS inputs
    - Inputs are structured to span and fill in a wide range of values
    - 3 x 7 x 400 = 8,400 futures
- Web Tool modeling time horizon is 30 years



<u>All operational strategies in the Web Tool will be modeled in all 8,400 combinations of inputs</u>

Hydrology

Hydrologic Uncertainty and DMDU

Not Enough

Single ensemble using only summary statistics

- Familiar
- Only one story
- Every ensemble has limitations
- Risk calculations are unreliable
- Ranges of reservoir elevations are not very useful

→

Appropriate in some contexts

Multiple ensembles using only summary statistics

- Somewhat familiar
- Multiple stories provide more context but not enough under deep uncertainty
- Every ensemble has limitations
- Risk calculations are unreliable and now competing
- Ranges of reservoir elevations are not very useful

→

Good

Multiple ensembles analyzed as individual traces

- New
- Multiple ensembles provide more traces and more data
- Individual trace analysis provides more information
- Ensembles may not cover range of uncertainty completely or evenly

→

Great in DMDU analysis

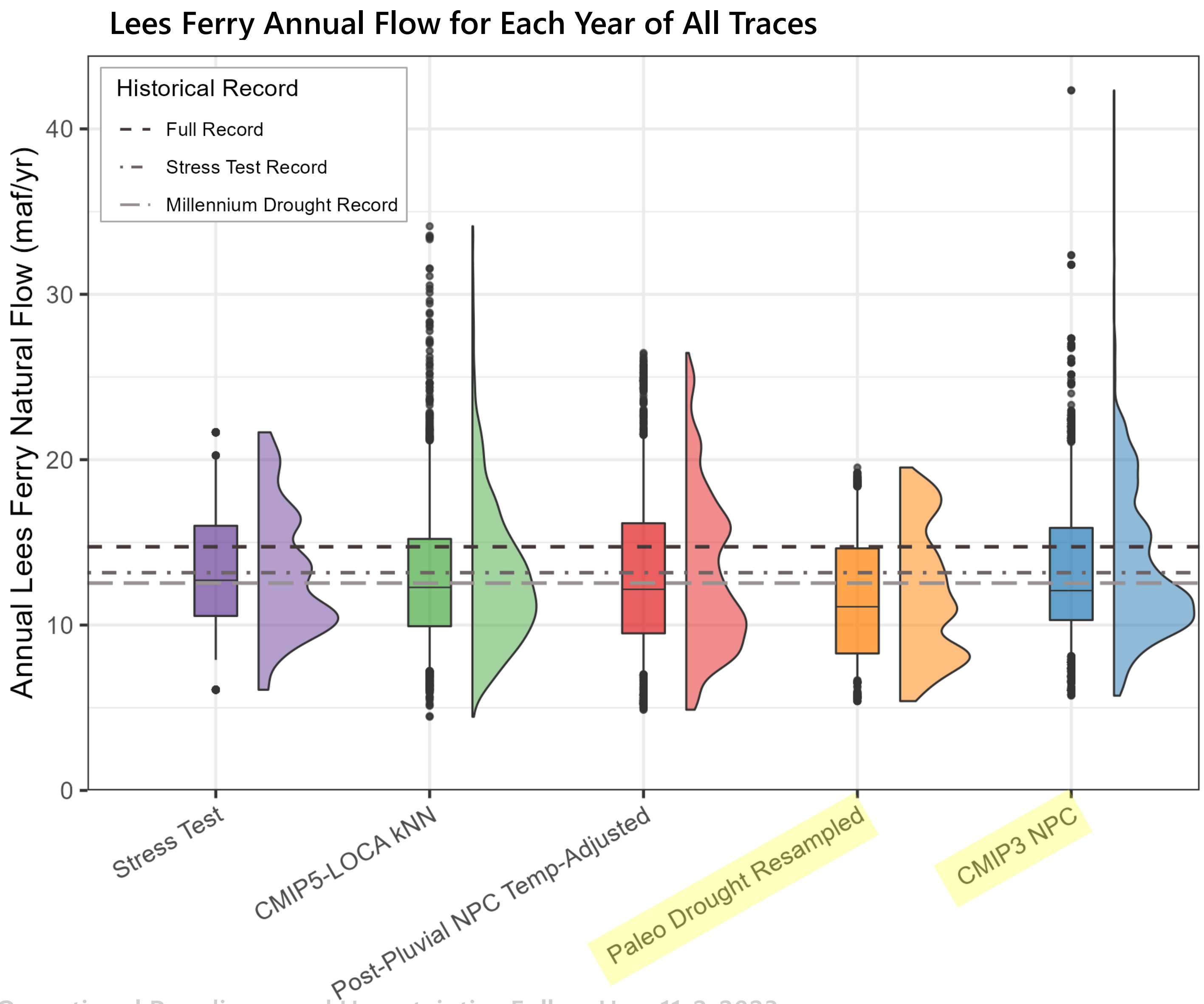
Multiple carefully chosen ensembles analyzed as individual traces

- New
- Multiple ensembles provide more traces and more data
- Chosen and generated ensembles ensure individual traces provide range and coverage to support reliable analysis

Advantage/Drawback/Limitation

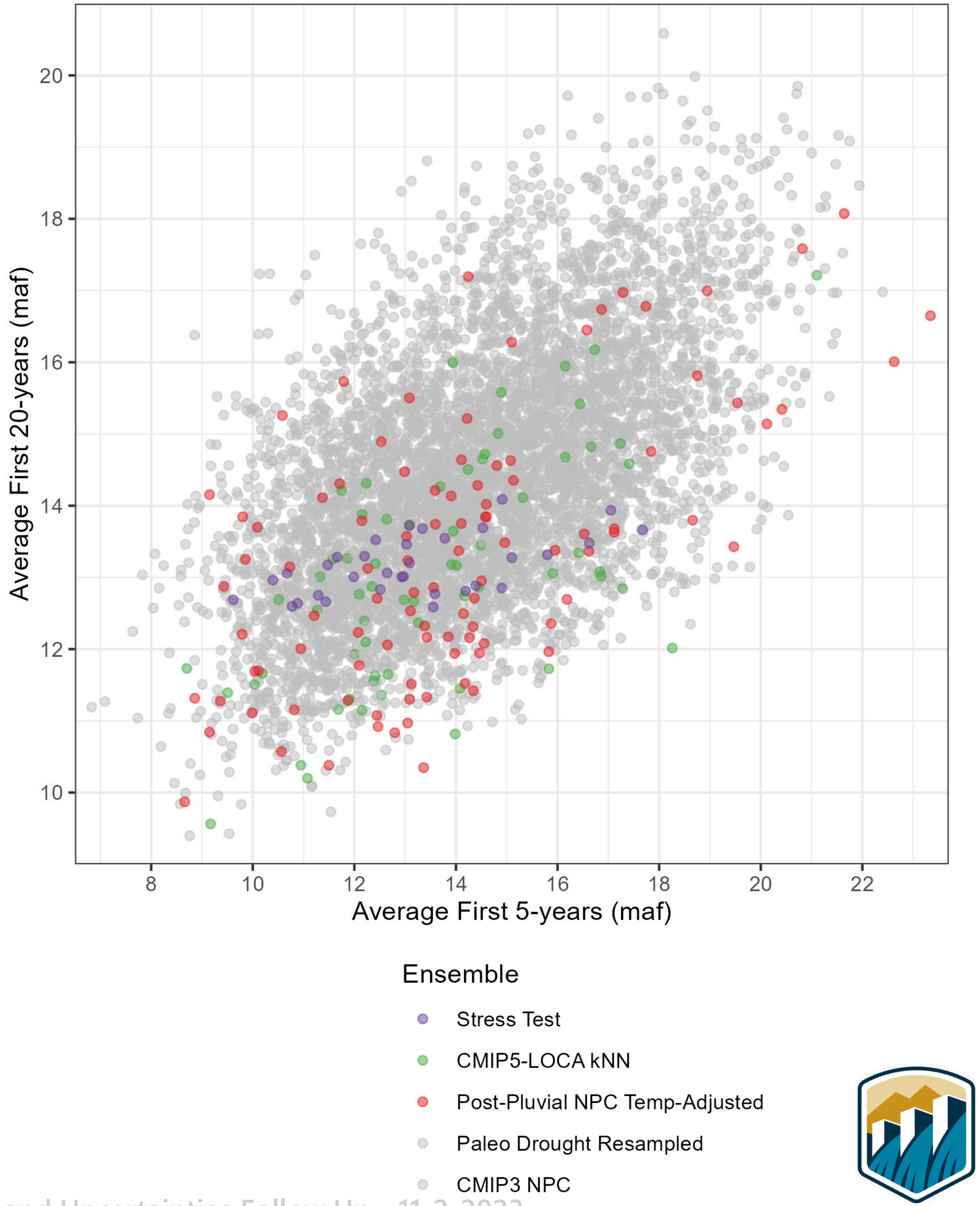
Web Tool Hydrology Ensembles

- Full ensembles
  - Stress Test (33 traces)
  - CMIP5-LOCA kNN (64 traces)
    - Coupled Model Intercomparison Project 5 (CMIP5)-Localized Constructed Analogs (LOCA) k-nearest neighbors (kNN)
  - Post-Pluvial NPC (nonparametric paleo-conditioned) Temp-Adjusted (100 traces)
- Selected traces from ensembles
  - Paleo Drought Resampled (50 traces)
  - CMIP3 NPC (153 traces)



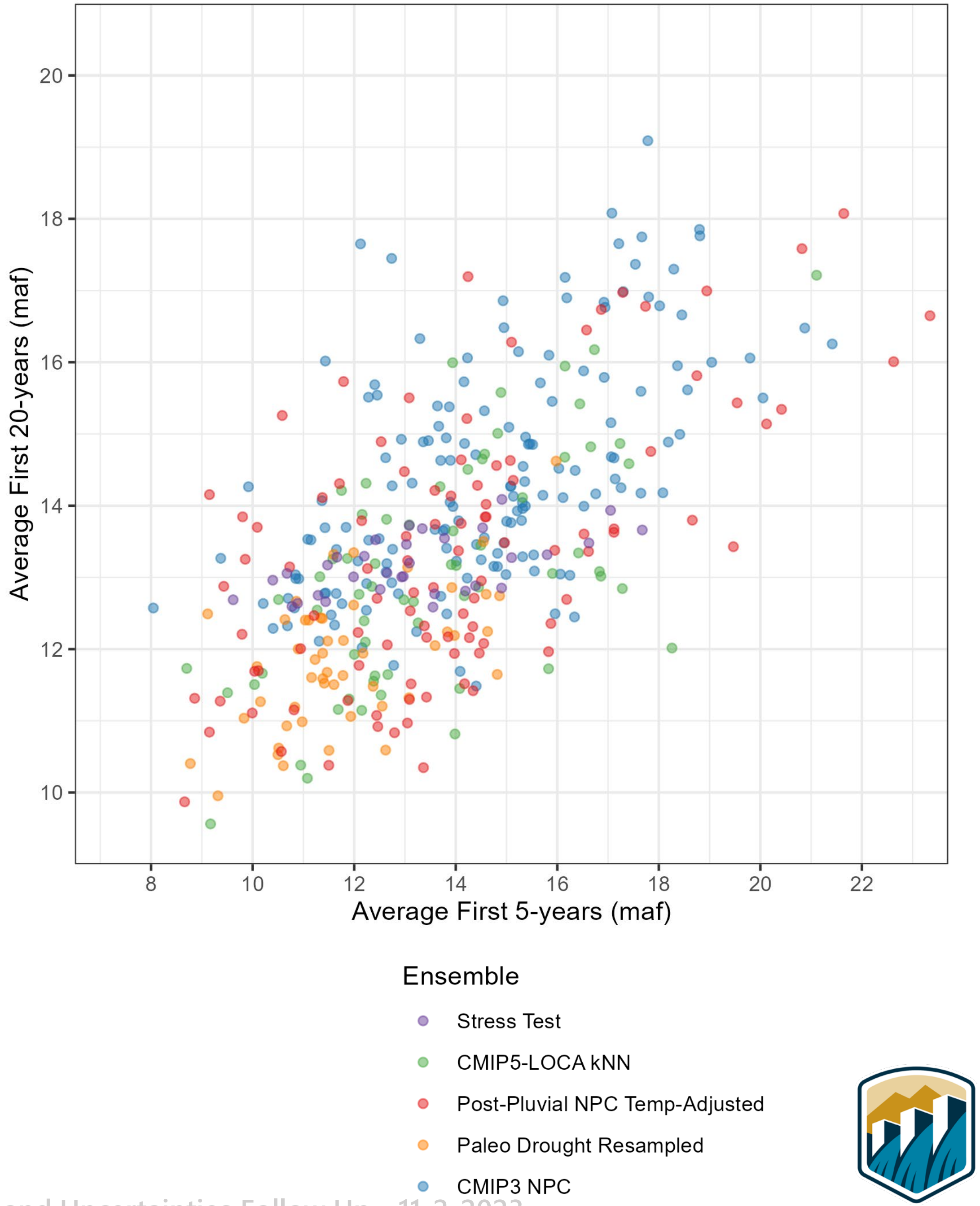
Motivation for Sampling

- The choice of ensembles used in the Web Tool was based on a combination of many characteristics
  - Data source
  - Previous applications
  - Range, distribution, trends, etc. (violin plots)
  - Static characteristics (5-yr avg, long-term avg)
  - Patterns
- Full ensembles (i.e., Stress Test, CMIP5-LOCA, Post-Pluvial NPC Temp-Adjusted) do not adequately span and fill a diverse range of patterns and characteristics to ensure sound DMDU analysis (colored dots)
- Chose/generated additional ensembles fill characteristics and patterns not covered by full ensembles (grey dots)
  - Paleo Drought Resampled (100 traces)
  - CMIP3 NPC (5,600 traces)
- No need to use all 5,700 traces – can sample from within ensembles and efficiently cover the gaps



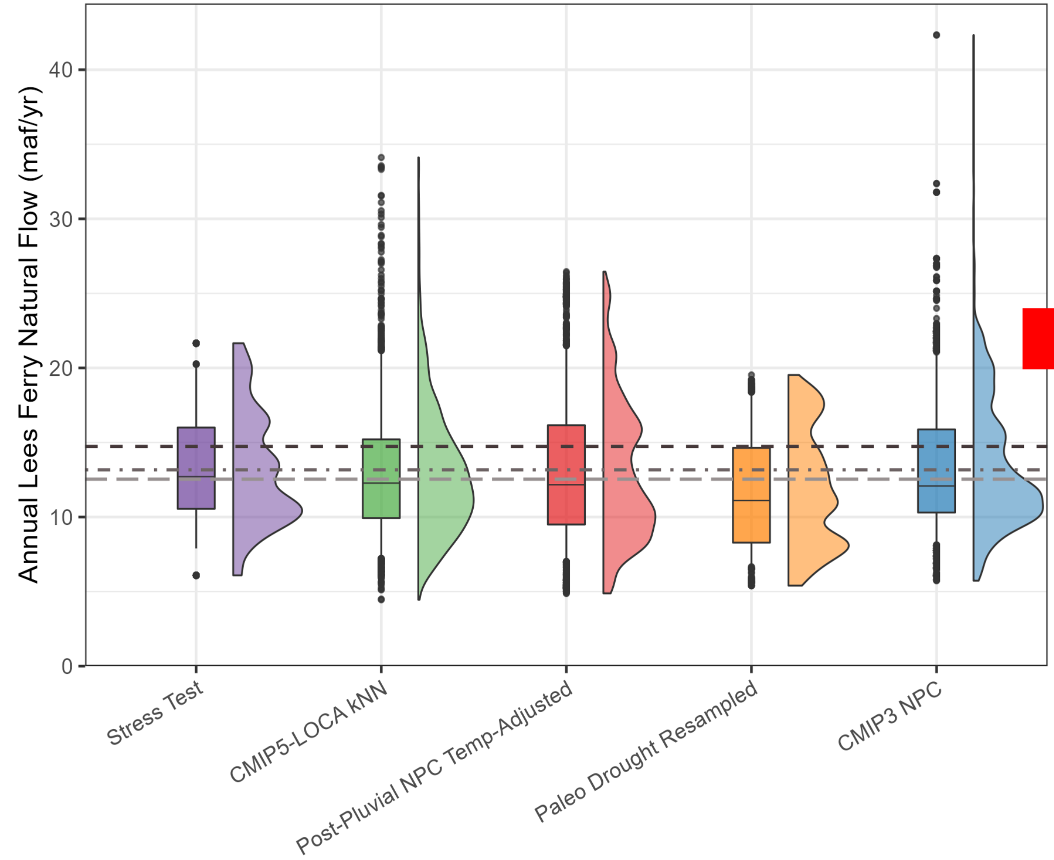
Approach to Strategically Sampling Traces

- Grouping traces by patterns
  - Machine learning algorithms were used to cluster traces from every candidate ensemble based on their patterns (see ITEW #3)
  - Resulted in 90 total clusters
- Sampling patterns (traces) from Paleo Drought Resampled and CMIP3 NPC ensembles
  - Sampled evenly across all clusters
  - Selected 50 representative traces from the Paleo Drought Resampled ensemble and 153 from the CMIP3 NPC ensemble from as many unique clusters as possible.
- Paleo Drought Resampled fills drier regions and patterns
- CMIP3 NPC ensemble has a broad range of flow characteristics and inter-annual patterns

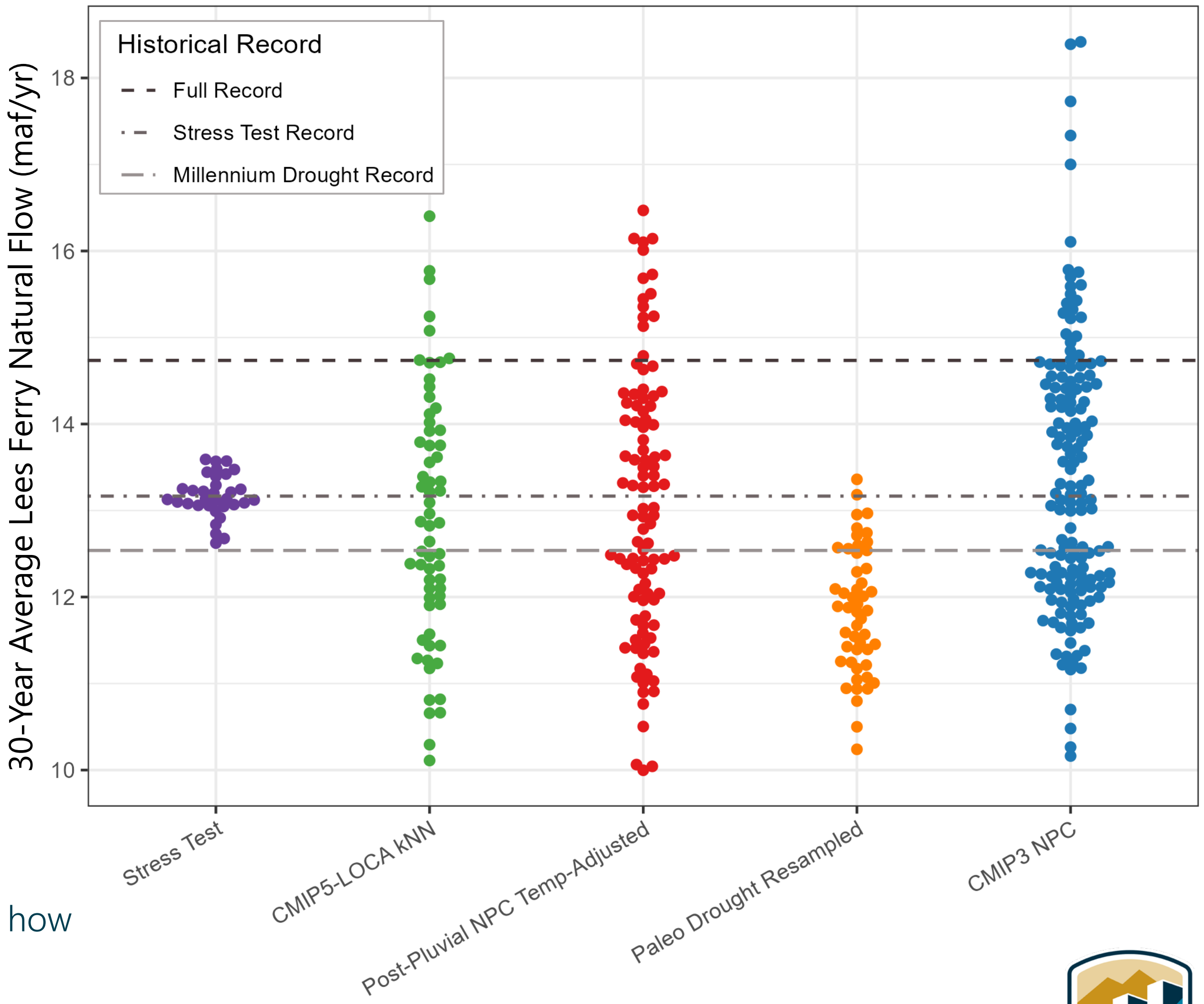


Summary of Hydrology Ensembles

Lees Ferry Annual Flow for Each Year of All Traces



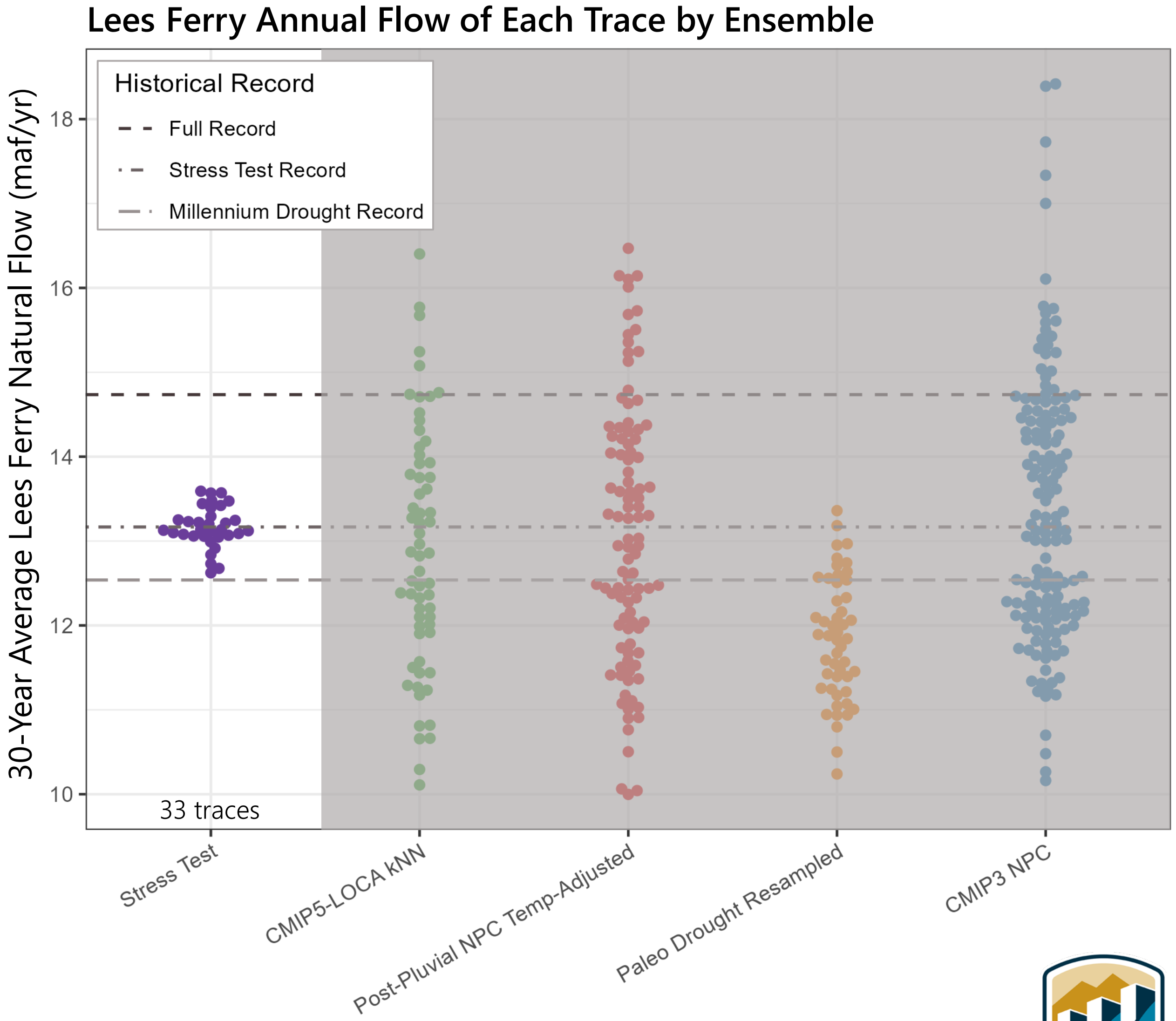
Lees Ferry Annual Flow of Each Trace by Ensemble



- Distributions of annual flows (boxplots and violins) do not provide information about sequencing, which is important to understanding how hydrology affects system conditions
- Visualizing each ensemble's individual hydrology traces is more valuable because they are all treated as independent futures in DMDU analysis

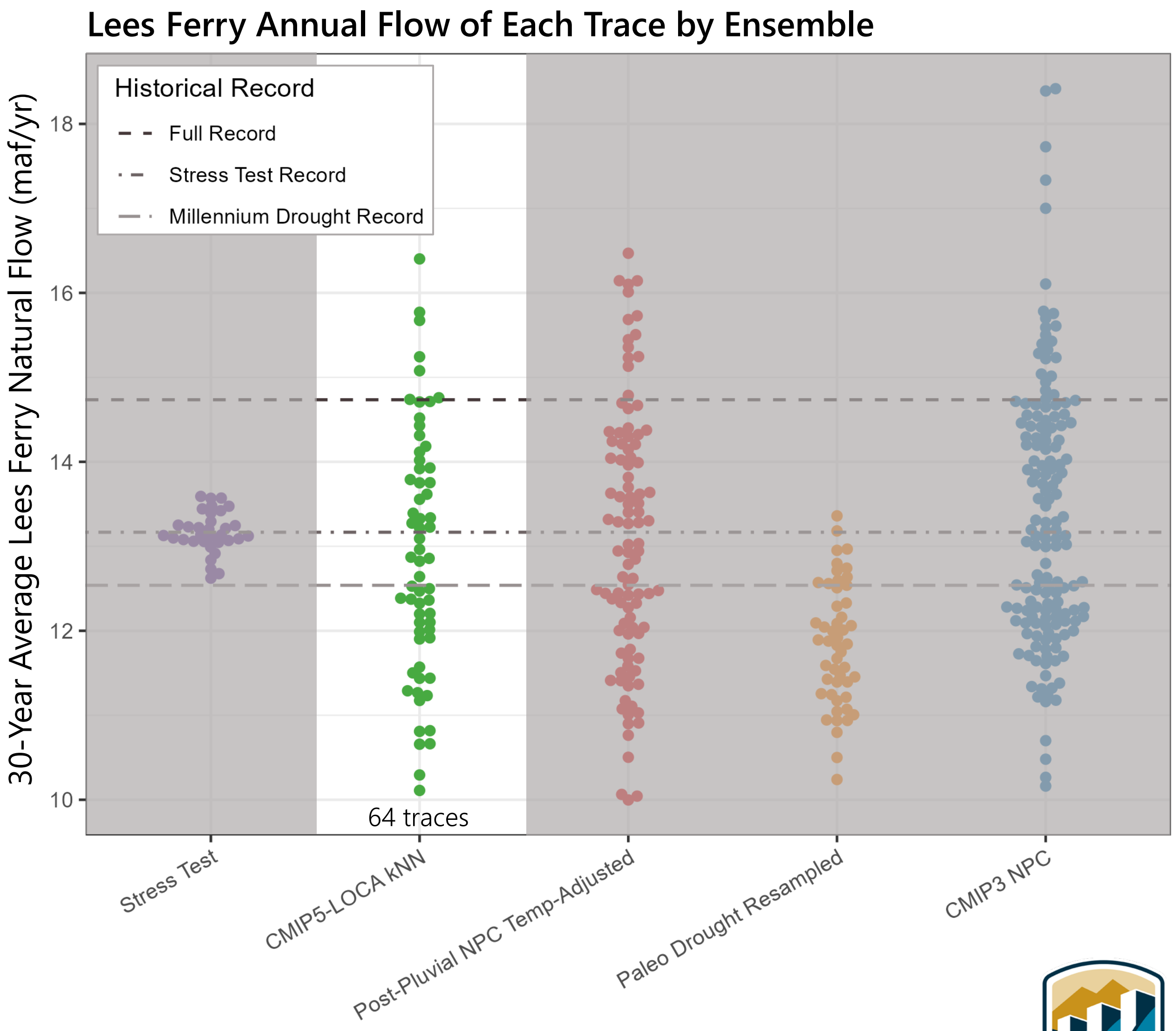
Stress Test

- Index sequential method (ISM)[3] using 1988-2020 historical natural flows
- Provides continuity/context based on use in previous studies
- Includes the effects of climate change over last ~30 years



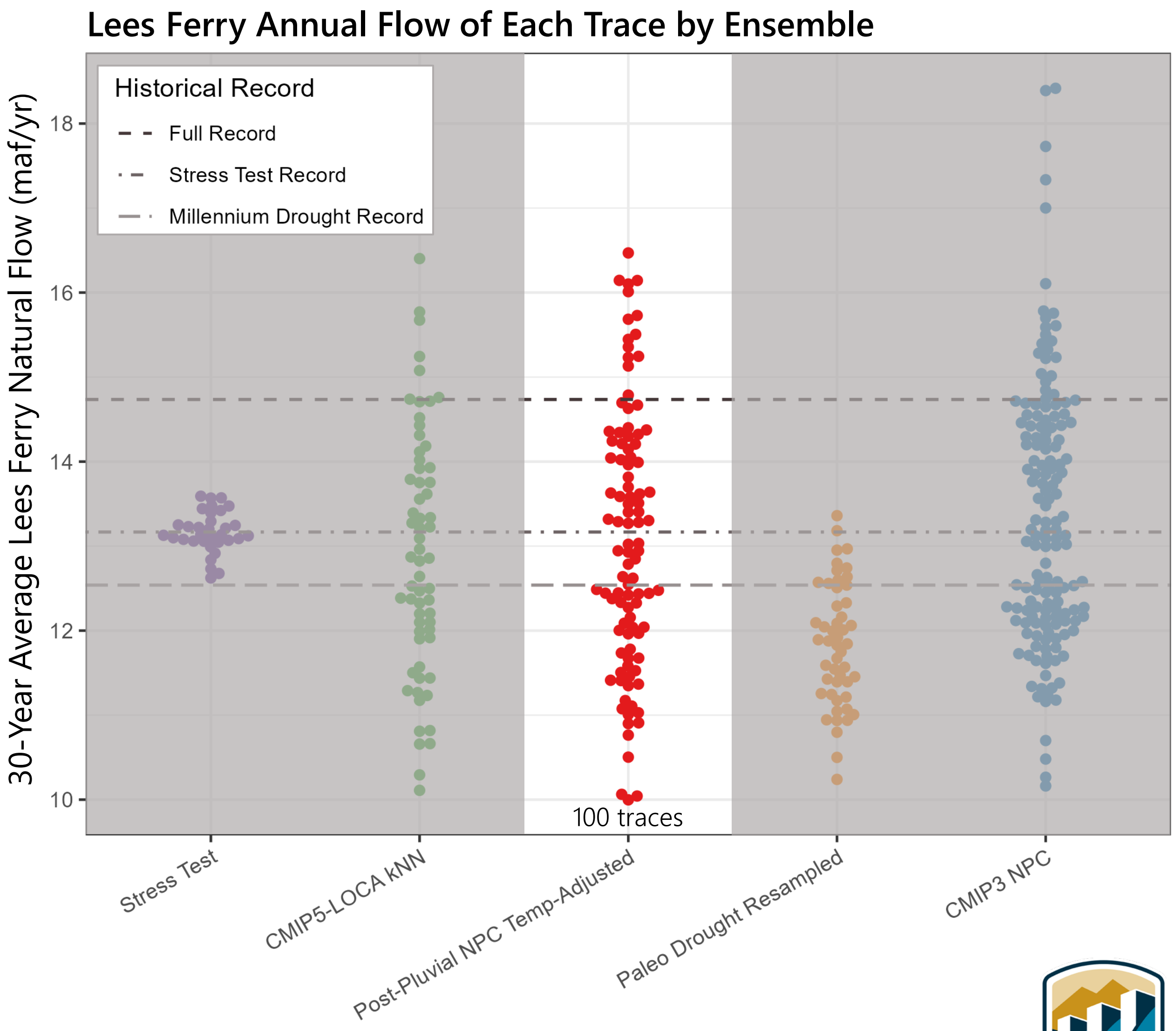
CMIP5 LOCA kNN

- Annual Lees Ferry flows from 2016 Reclamation LOCA downscaling effort
  - 64 projections, includes RCPs 4.5 and 8.5
  - Used flows from 2027 through 2056
- kNN used to disaggregate from Lees Ferry flows to other Upper Basin natural flow locations
- Uses best available climate change projections in best available form



Post-Pluvial NPC Temp-Adjusted

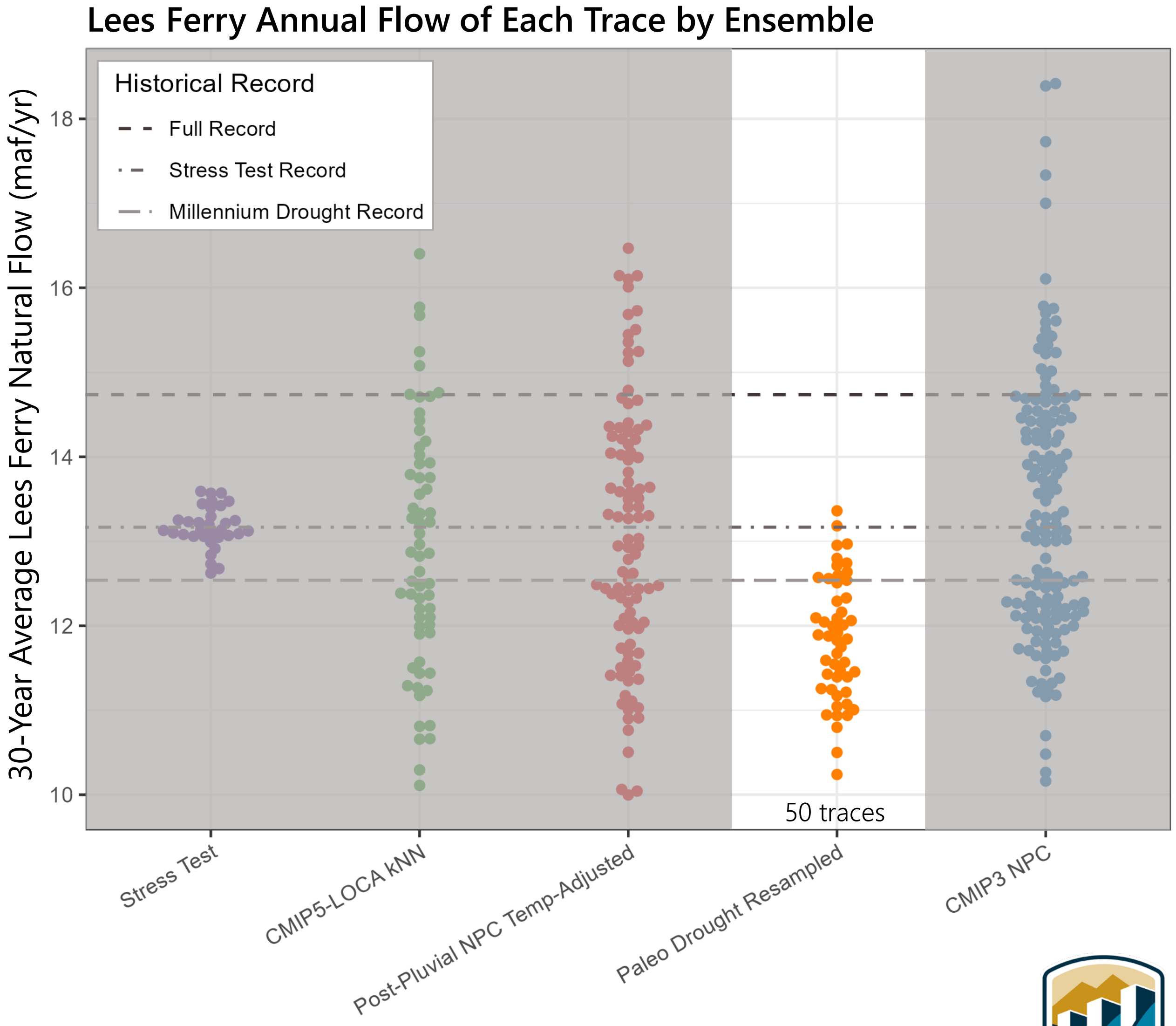
- Foundation is nonparametric paleo-conditioned[4] method using wet/dry sequences from Meko (2017)[5] paleo record and sampling 1931-2020 observed Lees Ferry magnitudes
- Temperature adjustment
  - Historical temperature trend extrapolated to produce declining streamflow trend
  - Temperature sensitivity based on Milly and Dunne (2020)[6]
  - High and low annual flow thresholds chosen to define bounds for variability
- Uses multiple historical data sources, incorporates a trend, maintains/increases variability; fills gap in larger set of ensembles



Paleo Drought Resampled

Selected Traces

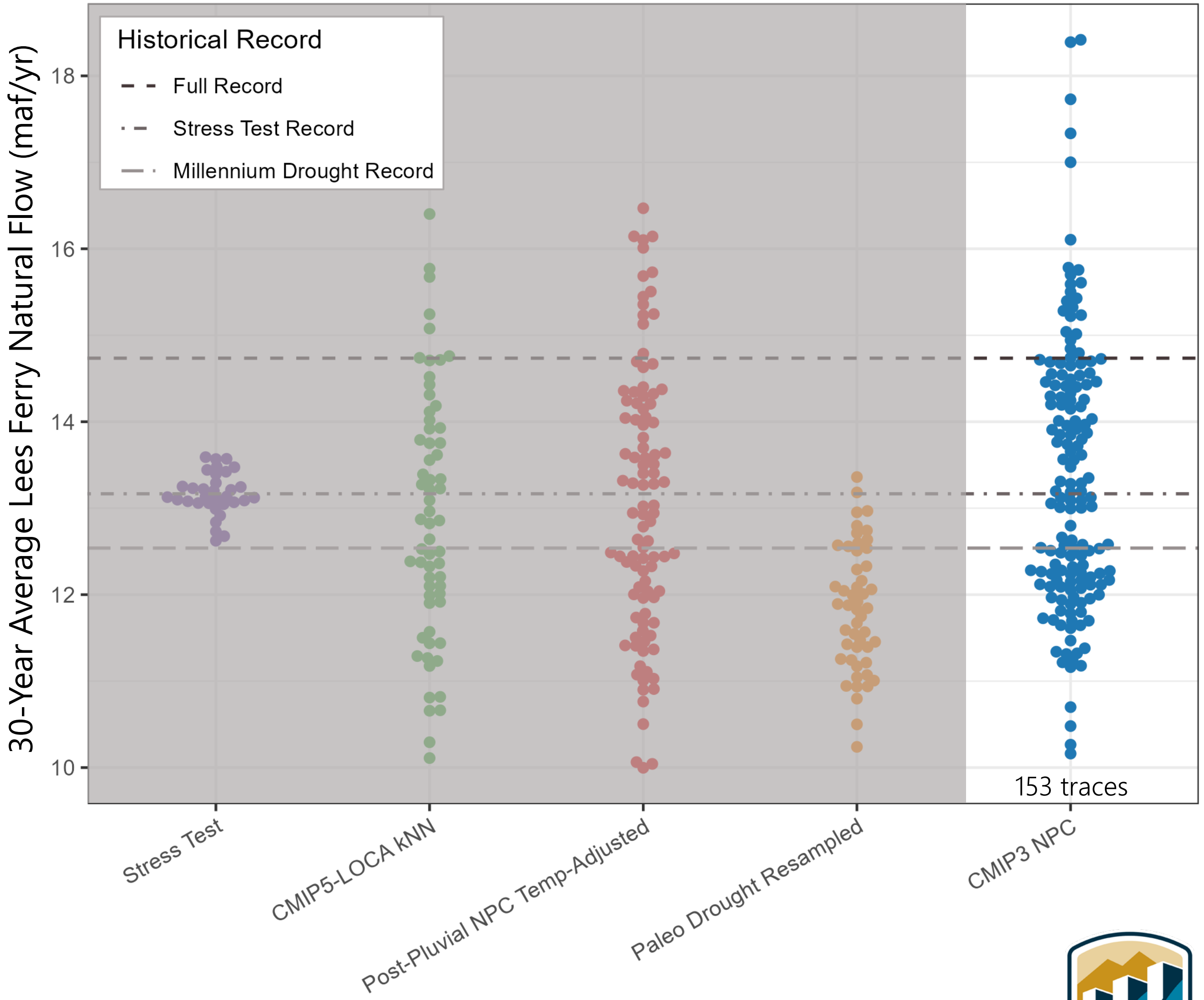
- Randomly resamples reconstructed 16th century drought
- Developed by Salehabadi and Tarboton at the Utah State University[7]
- Represents a severe drought scenario while including uncertainty in sequencing
- Subset of full Paleo Drought Resampled ensemble (50 traces selected from 100 traces)



CMIP3 NPC
Selected Traces

- Used Meko (2017) paleo record to define wet/dry sequences and sampled from annual CMIP3 flows to get magnitudes (and Basin-wide inputs)
  - 50 traces were generated from each 112 bias-corrected spatially downscaled (BCSD) projections (2024-2060), resulting in 5,600 traces for sampling
- Incorporates data from two valuable data sources and aligns with a recommendation from 2020 CRB Climate and Hydrology State of the Science Report[8]
- After analyzing patterns and features of other ensembles, we sampled 153 traces to fill gaps so that the dataset generated from all ensembles is better suited for DMDU analysis

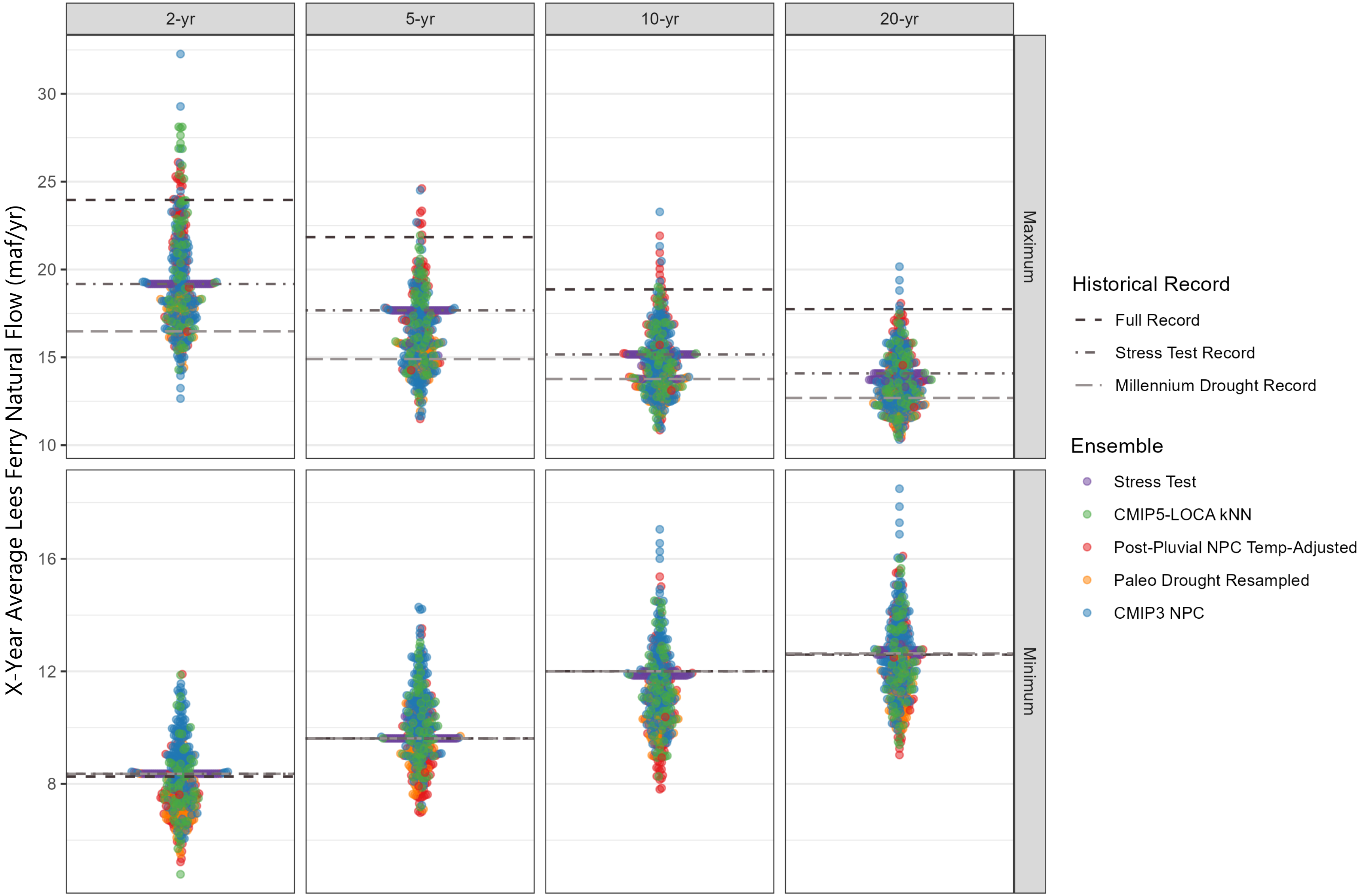
Lees Ferry Annual Flow of Each Trace by Ensemble



Hydrology Statistics

Maximum and Minimum X-Year Average Flow

- All ensembles are combined but colors show where certain ensembles are prevalent
- X-Year averages provide additional information on sequencing that can stress the system
- Covering a wide range of minimum and maximum flow sequences that extend beyond the observed record (especially on dry end)



How Traces are Used to Understand Vulnerability

- Modeling outcomes for individual hydrology traces are used to determine what hydrologic conditions could lead to vulnerability
- Web Tool traces are distributed widely and evenly to be able to capture vulnerability boundaries

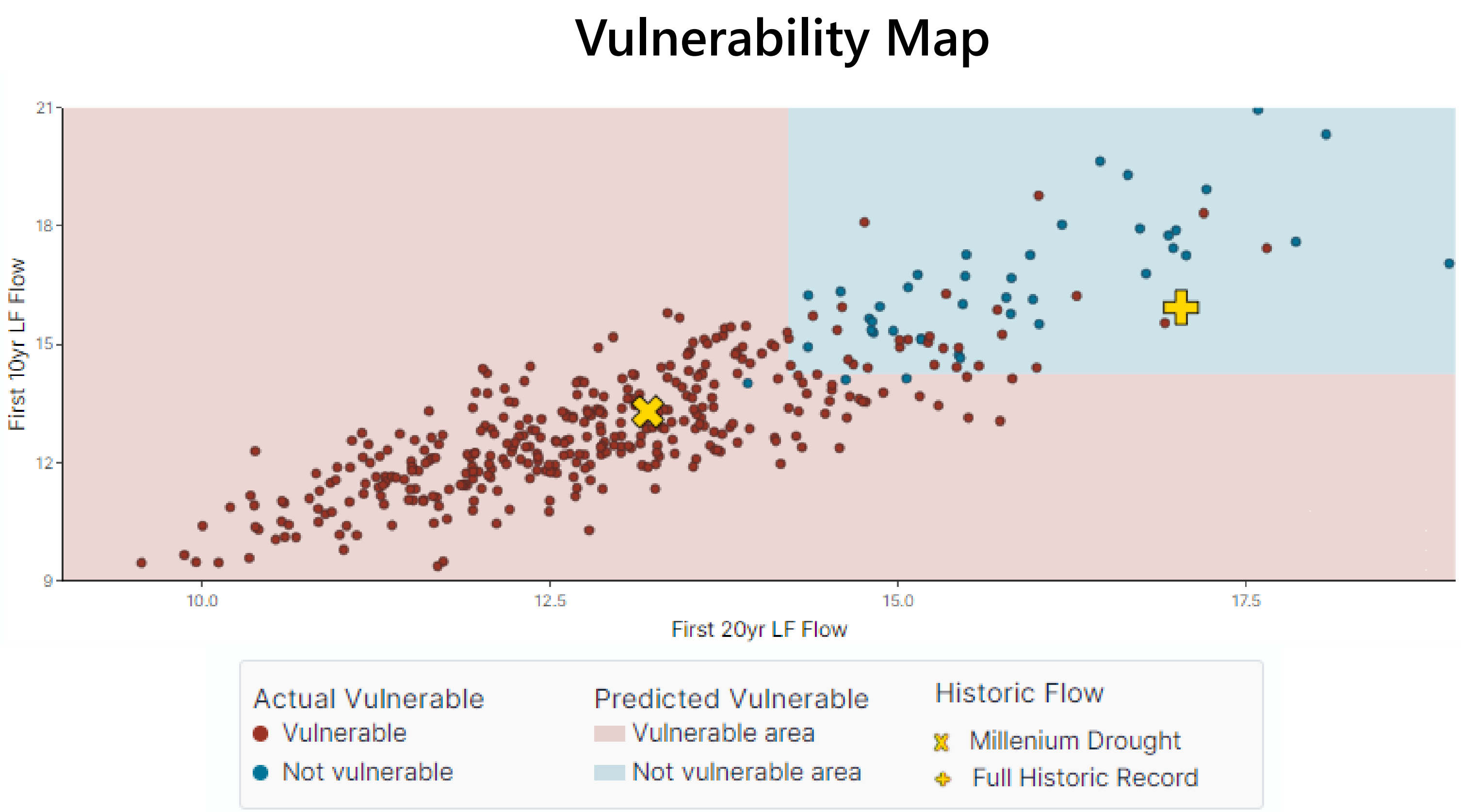
Vulnerability Definition

Powell < 3,525 feet in
more than 20% of months

OR

Mead < 1,050 feet in
more than 20% of months

in the first 20 years



Demands

Approach to Upper Basin Demands in Post-2026 Web Tool

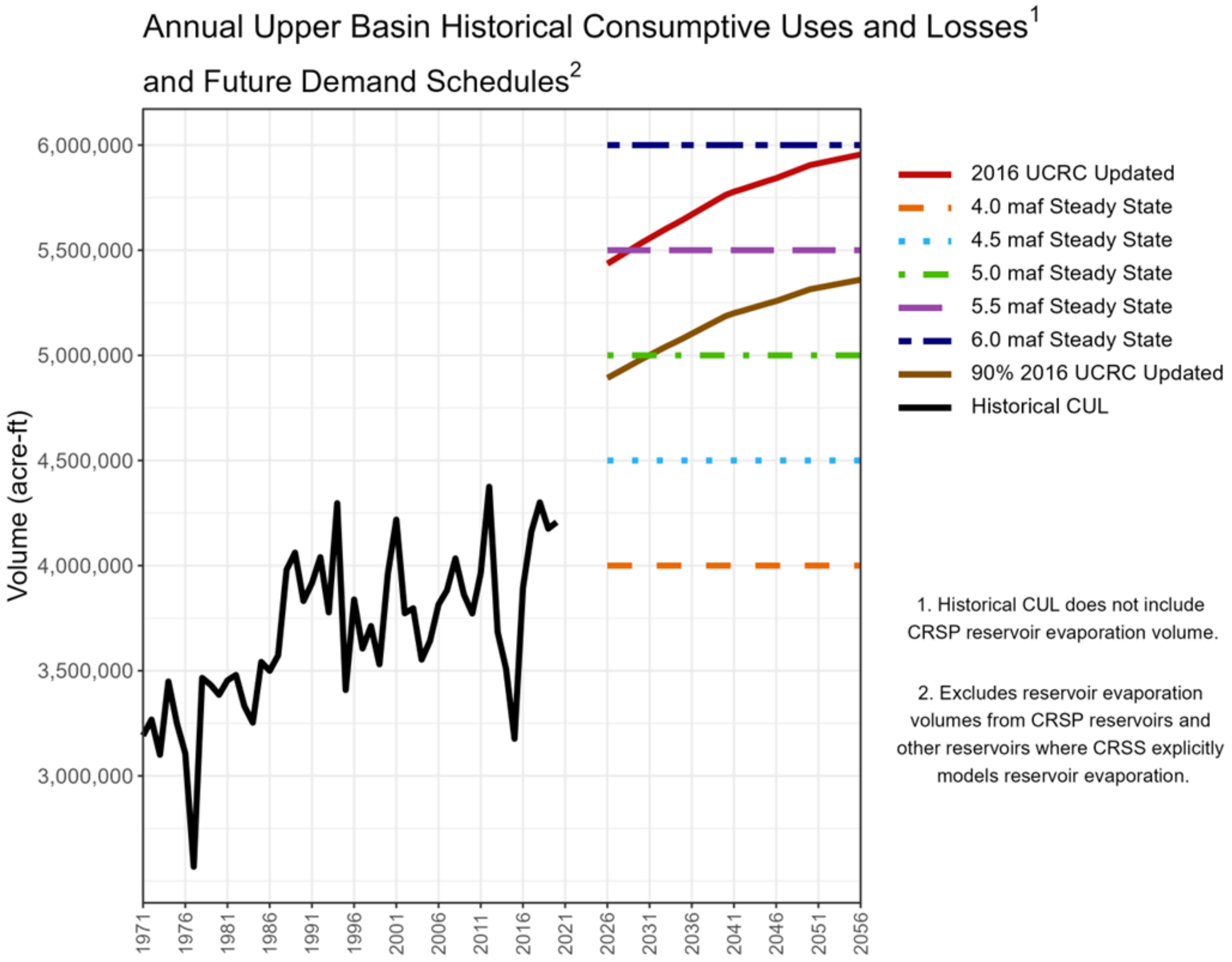
- Other long-term planning studies only used demand *scenarios*, or stories projecting how demands may evolve in the future
  - Valuable for considering how complex forces impact future water use
  - Embed assumptions about timing and magnitude of changes
  - Can obscure relationships between model inputs, reducing ability to identify conditions that drive system vulnerability
- Steady-state demand levels are appropriate for DMDU analysis
  - Need to span and fill in a range of potential future conditions, not create new stories about how water use will evolve
  - Want to avoid the layers of assumptions embedded in time-varying scenarios
  - DMDU is not seeking to identify system conditions at a specific point in time, just under a specific intersection of inputs; impacts of high or low steady-state demands are relevant at any point in the future
- Web Tool will use multiple demand scenarios along with different steady-state demand levels to help distinguish how combinations of inputs interact to result in system vulnerability

Rationale for Using a Variety of Upper Basin Demands

- General
  - Important to look at scenarios along with updated 2016 Upper Colorado River Commission (UCRC) schedule
  - Develop and understanding of intersection of demands, hydrology, and initial conditions on vulnerability
  - UB demand scenarios include a range of demands both below and above current use
- Multiple time-varying demand scenarios
  - Represent different assumptions about how quickly UB demands grow
- Steady-state demand levels
  - Helps isolate impacts of hydrology, demands, ICs, and operational strategy
  - When demands are constant, it simplifies the assessment of how demands contribute to vulnerability

Description of Web Tool Upper Basin Demand Schedules[1]

- Two time-varying demand scenarios
  - Updated 2016 Depletion Demand Schedule
    - Adopted by the Upper Colorado River Commission June 14, 2022
  - 90 percent of updated 2016 Depletion Demand Schedule
- Five steady-state demand levels[2]
  - 4.0 maf
  - 4.5 maf
  - 5.0 maf
  - 5.5 maf
  - 6.0 maf



[1] Variations on the Updated UCRC 2016 Depletion Demand Schedule for Upper Basin demands (including the steady-state demands) are included in this tool for sensitivity analysis only. Variations on the UCRC Depletion Demand Schedule do not represent projections or positions of any party on future Upper Basin demands.

[2] Excludes CRSP reservoir evaporation

Methods to Develop Web Tool Upper Basin Demand Schedules

- All Web Tool demands are based on updated 2016 UCRC Schedule
  - Tribal demands are informed by the 2018 Tribal Water Study
  - Reclamation assisted Upper Division States to disaggregate decadal schedule to the spatial and monthly timestep needed for CRSS
- 90% UCRC demands scale updated 2016 UCRC Schedule by 90%
- Approach to creating steady-state demands schedules
  - Scale updated 2016 UCRC Schedule to specified volume
  - Ratios for distributing steady-state demands are based on year 2042, the mid-point of the Web Tool’s simulation horizon (2027-2056)

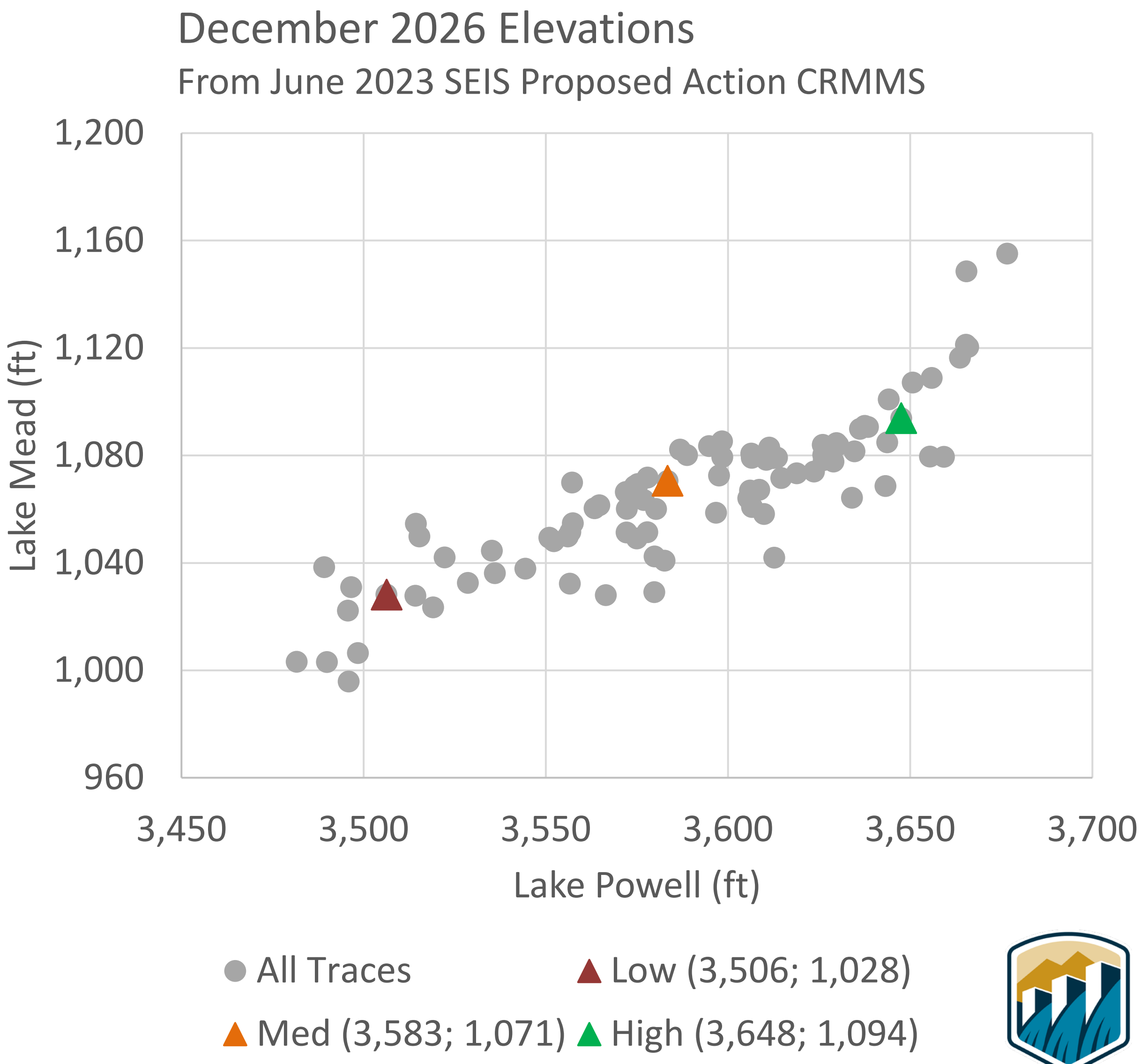
Approach to Lower Basin Demands in the Post-2026 Web Tool

- Unless modified by an operational strategy, demands in the Lower Basin are 9.0 maf (7.5 maf to US, 1.5 maf to Mexico)
  - The different Lower Basin Delivery concepts allow for various delivery reductions (and increases) to be applied to the basic apportionments
  - Delivery reductions up to 9 maf/year can be explored in the Web Tool
- Distribution of Lower Basin delivery reductions will not be represented in Web Tool modeling
  - Lake Mead releases will be reduced as specified by a given policy, enabling analysis of reservoir levels

Initial Conditions

Range of Initial Conditions in Web Tool

- We do not know what the contents of Lake Powell and Lake Mead will be when we adopt new operating guidelines
- Results (e.g., vulnerability analysis) are sensitive to initial reservoir contents, particularly in the first ~1-10 years
- A "reasonable" range of initial conditions (reservoir contents, Powell release, etc.) are used to address this uncertainty
- Selected three sets of initial conditions from the June 2023 SEIS Proposed Action CRMMS model projections of December 31, 2026 conditions
  - These traces are used to provide all required initialization data in CRSS, e.g., other Upper Basin reservoirs



How Different Upper Basin Demands and Initial Conditions Affect Vulnerability: A Demonstration

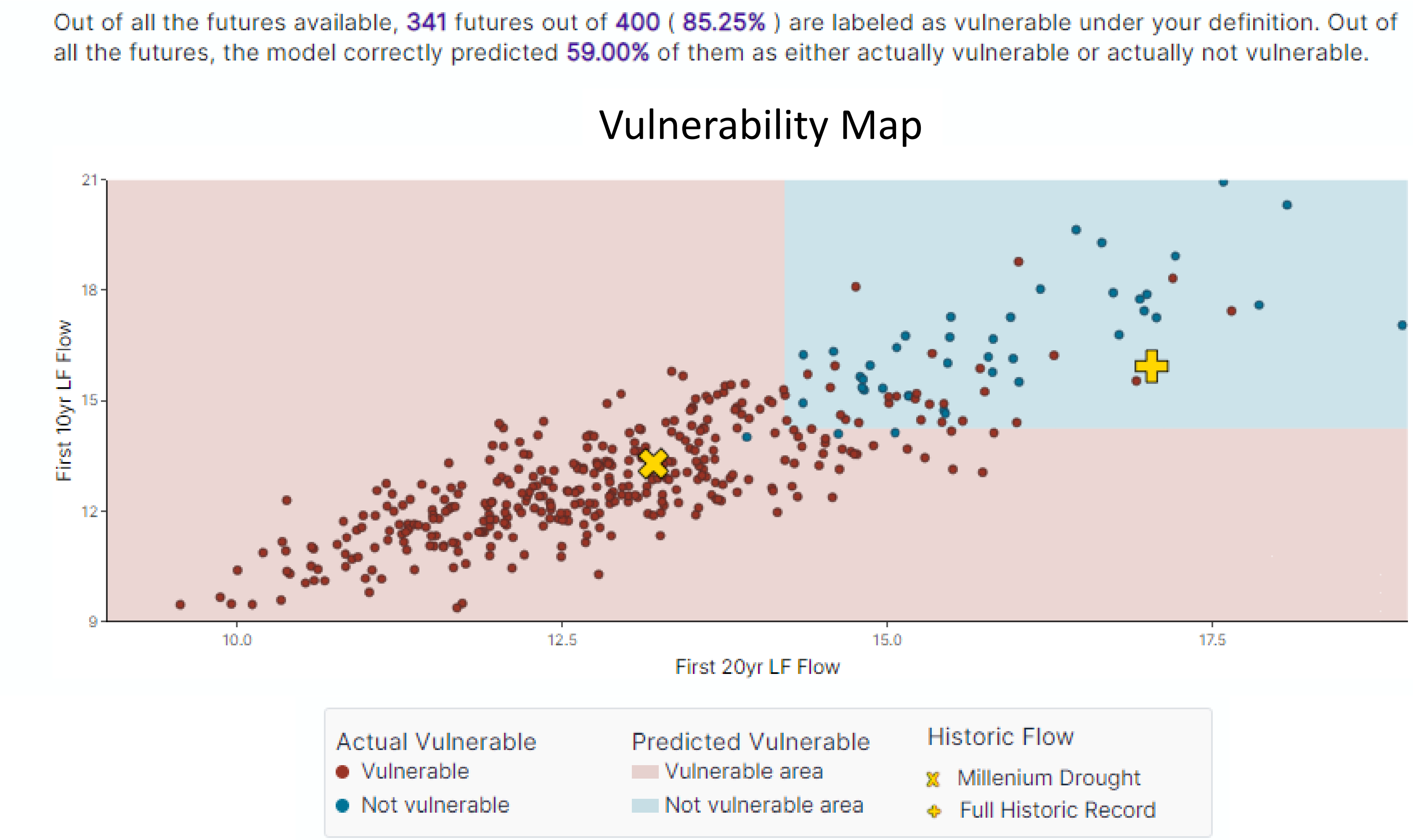
6 maf Steady-State UB Demands with Low Initial Conditions

Powell < 3,525 feet in more than 20% of months

OR

Mead < 1,050 feet in more than 20% of months

in the first 20 years



4 maf Steady-State UB Demands with Low Initial Conditions

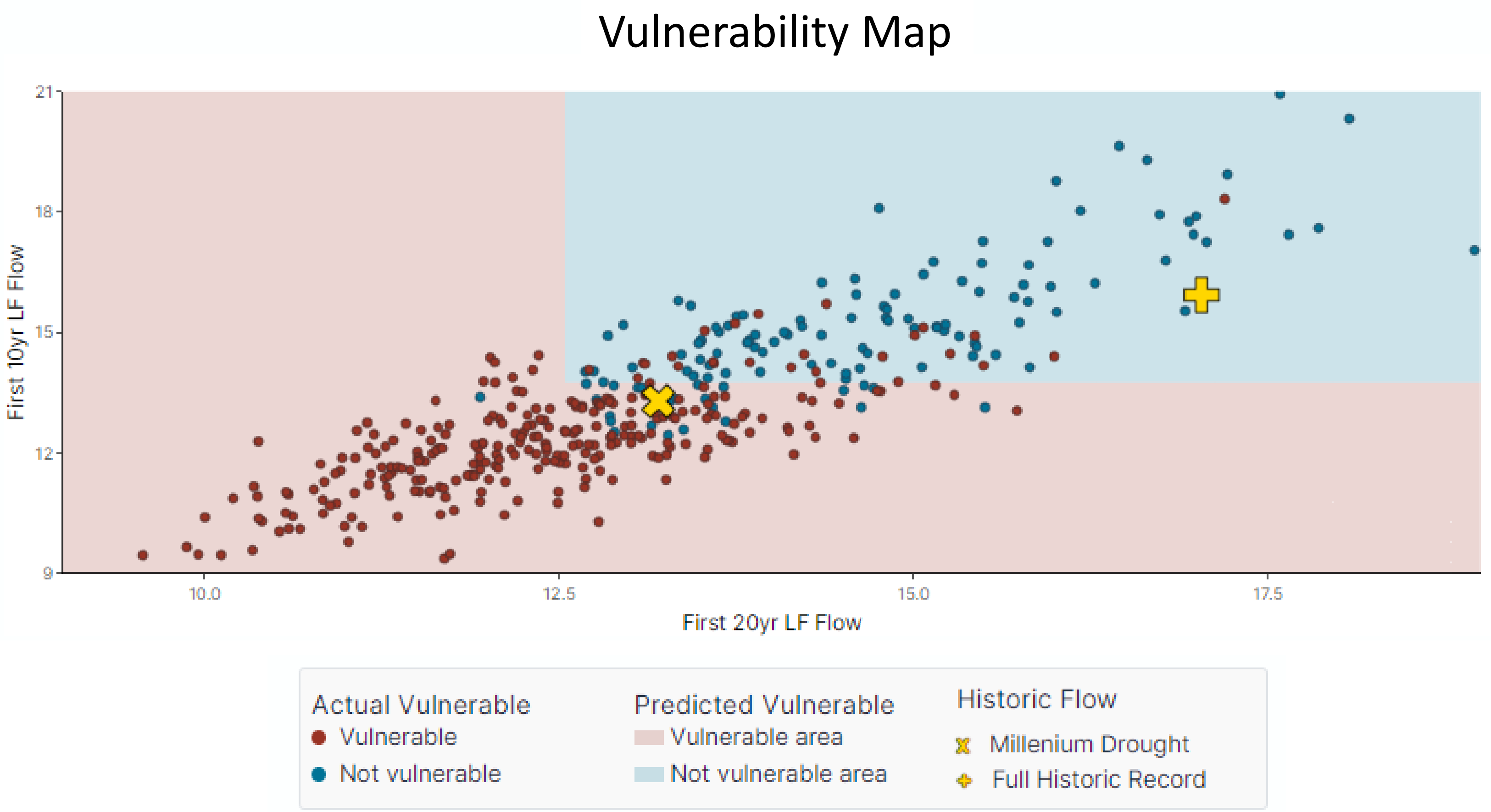
Powell < 3,525 feet in more than 20% of months

OR

Mead < 1,050 feet in more than 20% of months

in the first 20 years

Out of all the futures available, **278** futures out of **400** (**69.50%**) are labeled as vulnerable under your definition. Out of all the futures, the model correctly predicted **74.25%** of them as either actually vulnerable or actually not vulnerable.

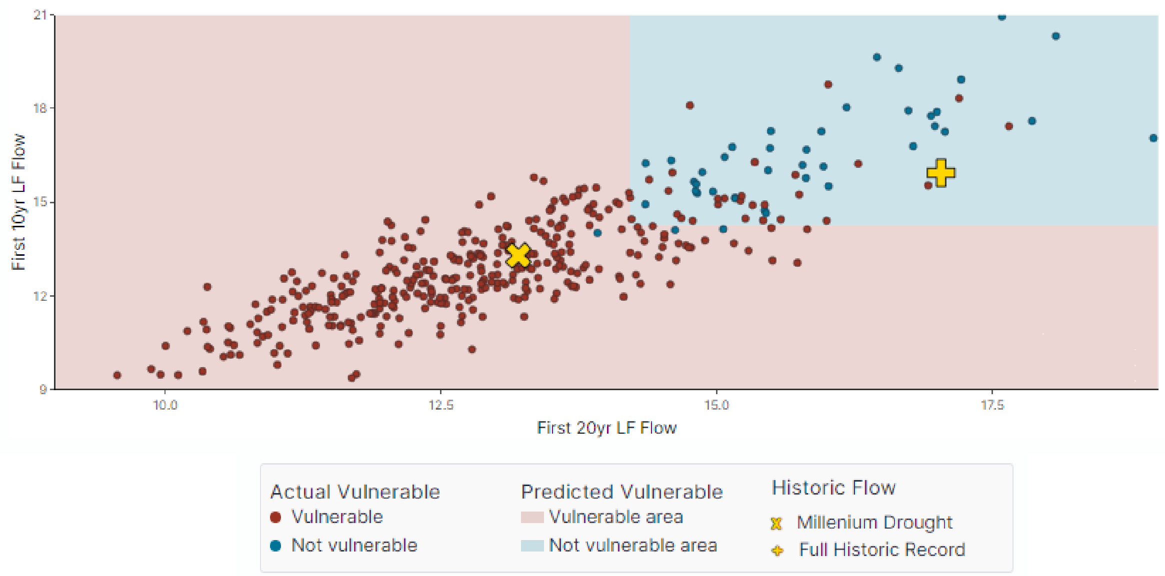


Vulnerability Comparison for Different Demand Levels

6 maf Steady-State UB Demands + Low ICs
341 out of 400 (85.25%) vulnerable

Out of all the futures available, 341 futures out of 400 (85.25%) are labeled as vulnerable under your definition. Out of all the futures, the model correctly predicted 59.00% of them as either actually vulnerable or actually not vulnerable.

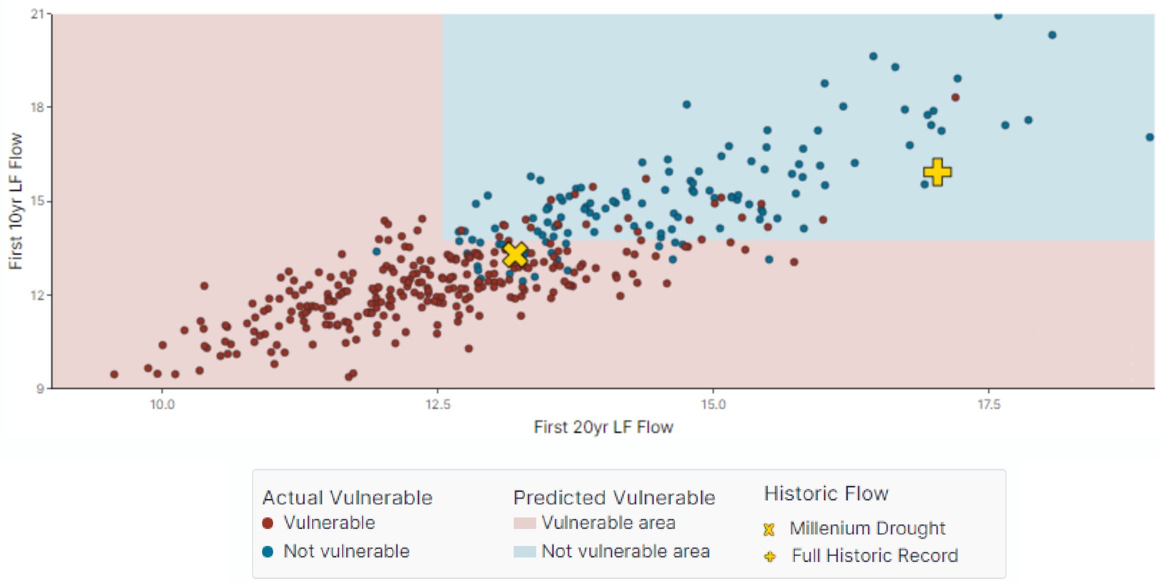
Vulnerability Map



4 maf Steady-State UB Demands + Low ICs
278 out of 400 (69.50%) vulnerable

Out of all the futures available, 278 futures out of 400 (69.50%) are labeled as vulnerable under your definition. Out of all the futures, the model correctly predicted 74.25% of them as either actually vulnerable or actually not vulnerable.

Vulnerability Map



4 maaf Steady-State UB Demands with Mid Initial Conditions

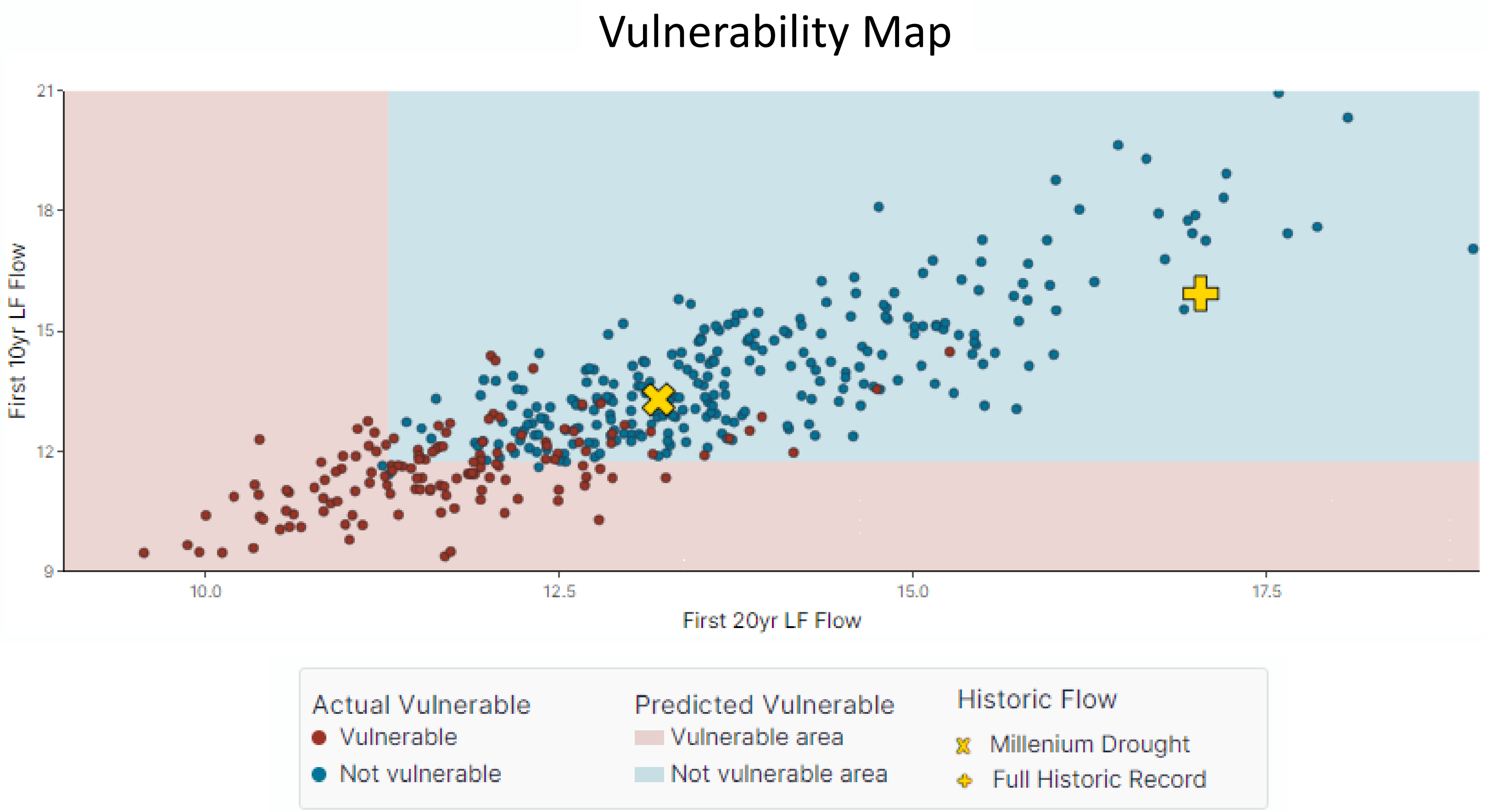
Powell < 3,525 feet in more than 20% of months

OR

Mead < 1,050 feet in more than 20% of months

in the first 20 years

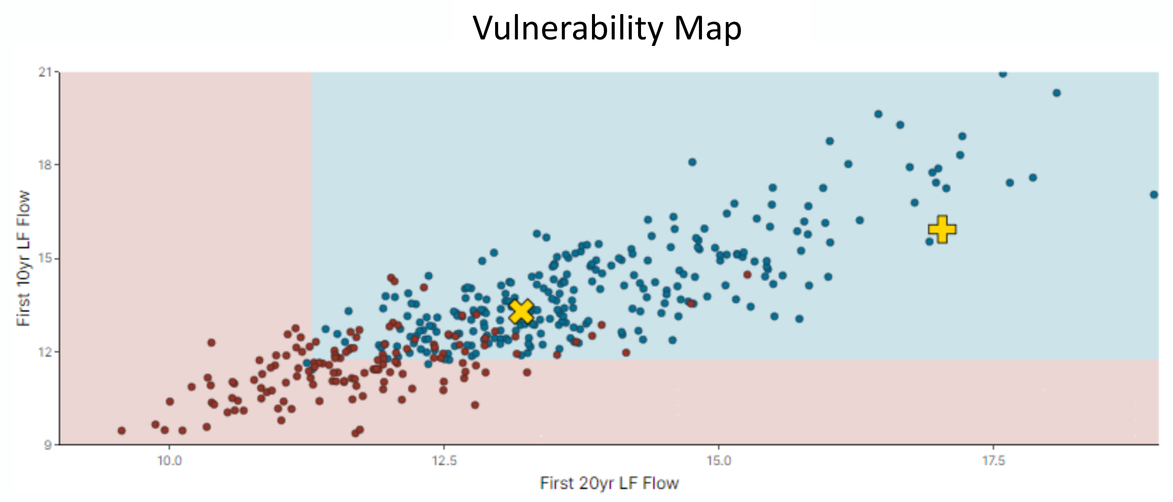
Out of all the futures available, **137** futures out of **400** (**34.25%**) are labeled as vulnerable under your definition. Out of all the futures, the model correctly predicted **84.50%** of them as either actually vulnerable or actually not vulnerable.



Vulnerability Comparison for Different Initial Conditions

4 maf Steady-State UB Demands + Mid ICs
137 out of 400 (34.25%) vulnerable

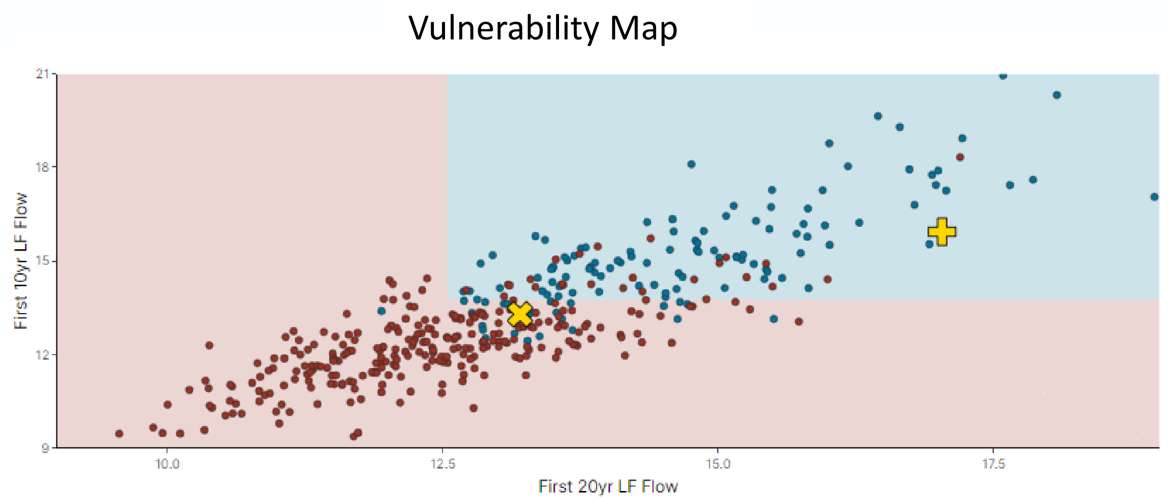
Out of all the futures available, 137 futures out of 400 (34.25%) are labeled as vulnerable under your definition. Out of all the futures, the model correctly predicted 84.50% of them as either actually vulnerable or actually not vulnerable.



Actual Vulnerable: Vulnerable; Not vulnerable
Predicted Vulnerable: Vulnerable area; Not vulnerable area
Historic Flow: Millenium Drought; Full Historic Record

4 maf Steady-State UB Demands + Low ICs
278 out of 400 (69.50%) vulnerable

Out of all the futures available, 278 futures out of 400 (69.50%) are labeled as vulnerable under your definition. Out of all the futures, the model correctly predicted 74.25% of them as either actually vulnerable or actually not vulnerable.



Actual Vulnerable: Vulnerable; Not vulnerable
Predicted Vulnerable: Vulnerable area; Not vulnerable area
Historic Flow: Millenium Drought; Full Historic Record

Session Summary

- Reclamation used flexible versions of CRSSv6 to enable Web Tool users to model a wide range of operational strategies across 48 customizable paradigms
- The Web Tool provides insight into the performance of various operational strategies and the volumes of conservation or water use reductions needed to stabilize the system
- The Web Tool is populated with ~200 seed strategies that provide an immediate pool of interesting strategies, a basis for comparison and a source of potential new ideas
- The hydrology, Upper Basin demand schedules and initial conditions inputs used to explore impacts of different uncertainties in the Web Tool modeling cover a wide range of conditions and support critical analysis

Future Sessions and Request for Input

- Future ITEW session topics include
  - Web tool intro and training
  - Sessions on additional technical topics may be offered upon request
- Future sessions
  - November 8: Web Tool training (Denver Federal Center)
  - November 14: Web Tool training (University of Colorado Boulder facilities)
- Please send questions, feedback, and requests for topics to bor-sha-crbpost2026@usbr.gov

Thank You

BUREAU OF RECLAMATION

References & Resources

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