BUREAU OF RECLAMATION

ITEW Session 2: Colorado River Simulation System (CRSS)

Webinar and In-Person (Denver, CO)

May 3, 2023

Agenda

- Welcome & Introductions
- Review Purpose of Group
- Review of Decision Making under Deep Uncertainty (DMDU) and the Post-2026 Technical Framework
- CRSS: Background
- Working Lunch
- CRSS: Technical Overview
- Policy Modeling Demo
- Policy Comparison
- Wrap Up & Future Sessions

Welcome & Introductions

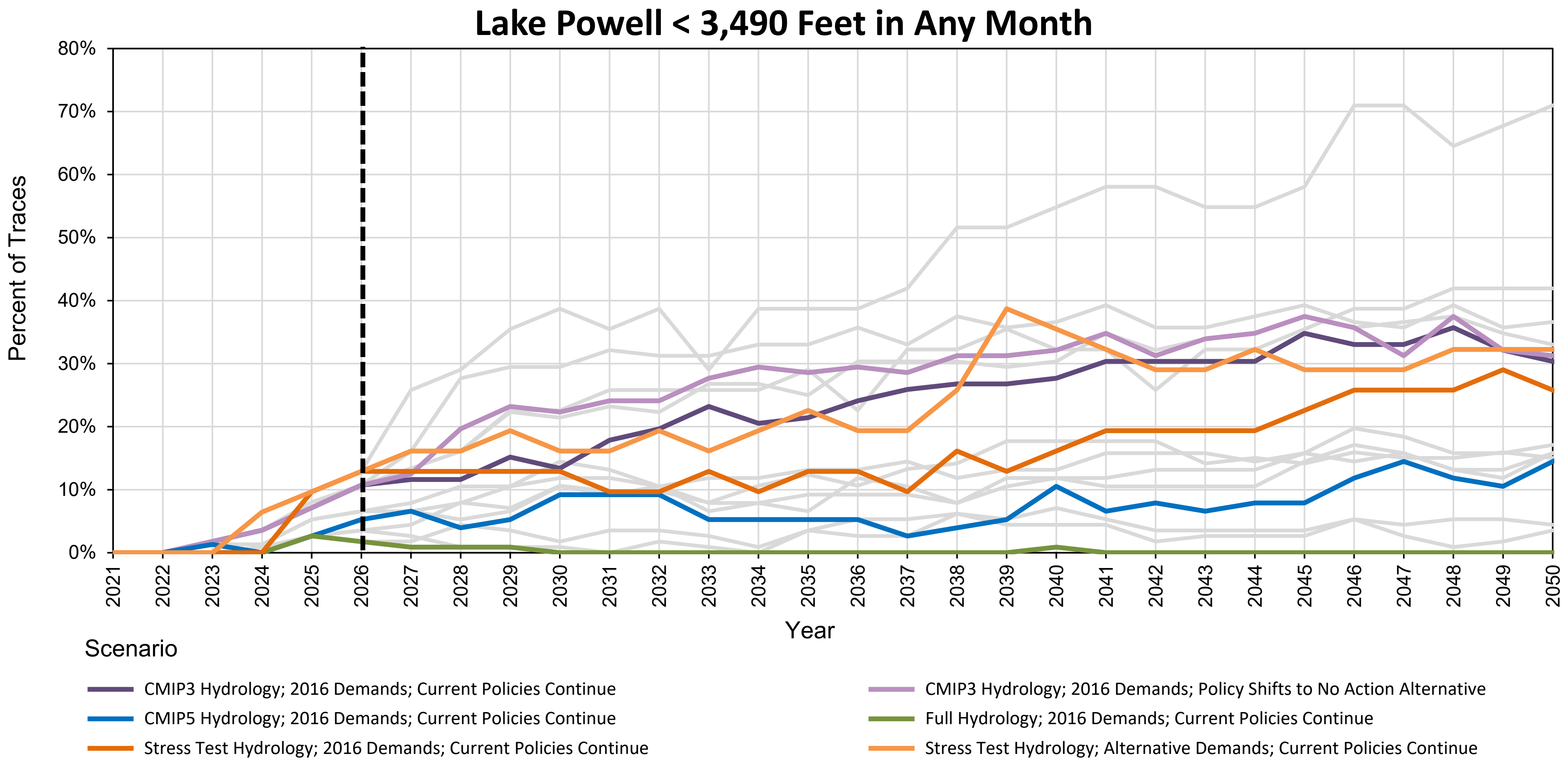
- This is the 2nd session of Reclamation's Integrated Technical Education Workgroup (kickoff session was December 7, 2022)
- The Technical Workgroup is being formed for the purpose of assisting our partners and stakeholders to gain a better understanding of the technical tools and approaches to be used 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 into 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

Review of DMDU and the Post-2026 Technical Framework

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



*All projections are from August 2020 CRSS modeling with Lake Powell initial elevation of 3,592’. Lake Powell’s current elevation is ~3,525’
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

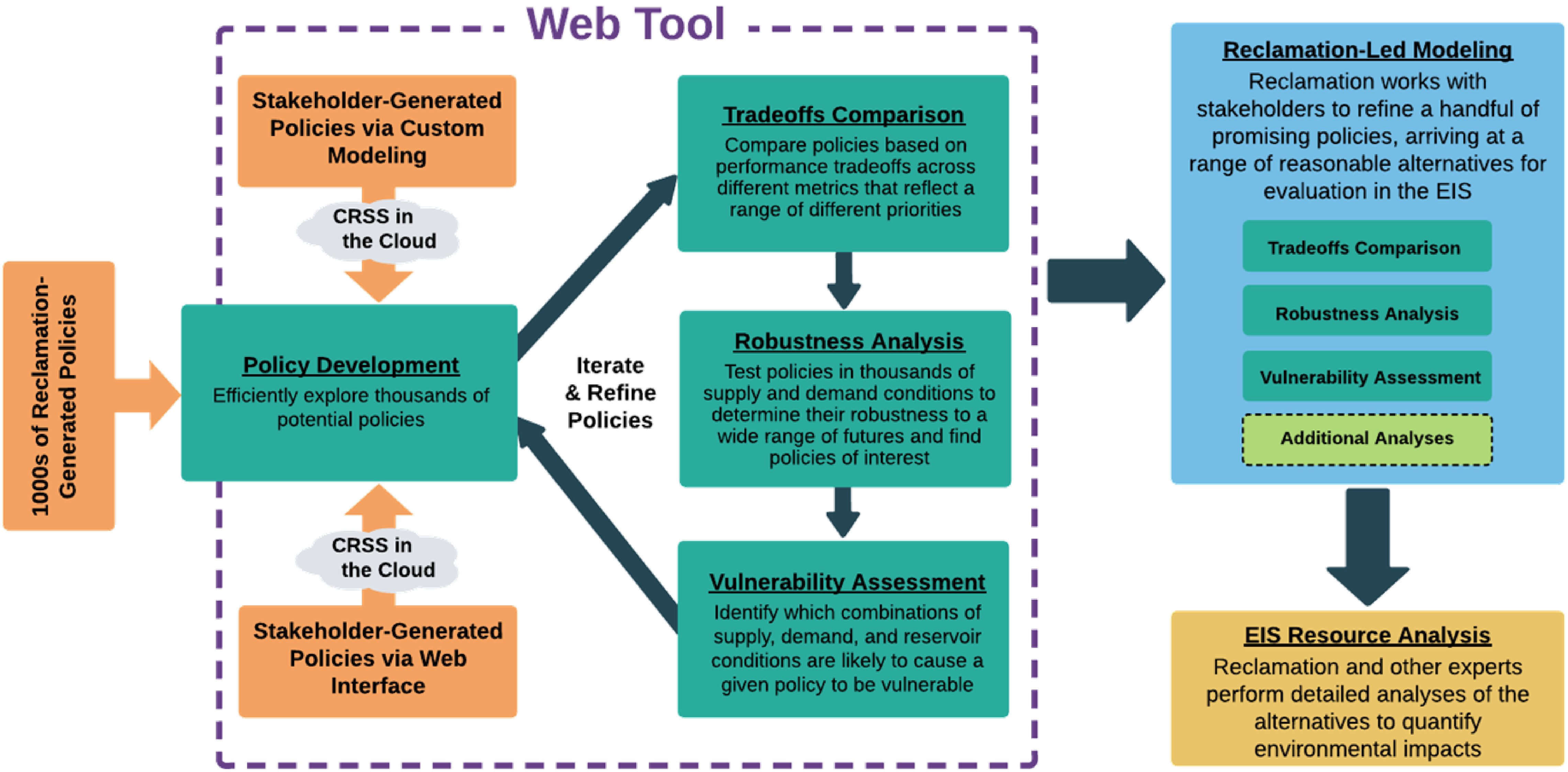
- Consider a *wide range* of future conditions without assigning likelihood beforehand
- Prioritize *robustness*, or the ability of a policy to perform acceptably well in a wide range of conditions
- Assess the *vulnerability* of a policy: what uncertain future conditions might cause it to fail?

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]

MORDM & the Web Tool in the Post-2026 Process



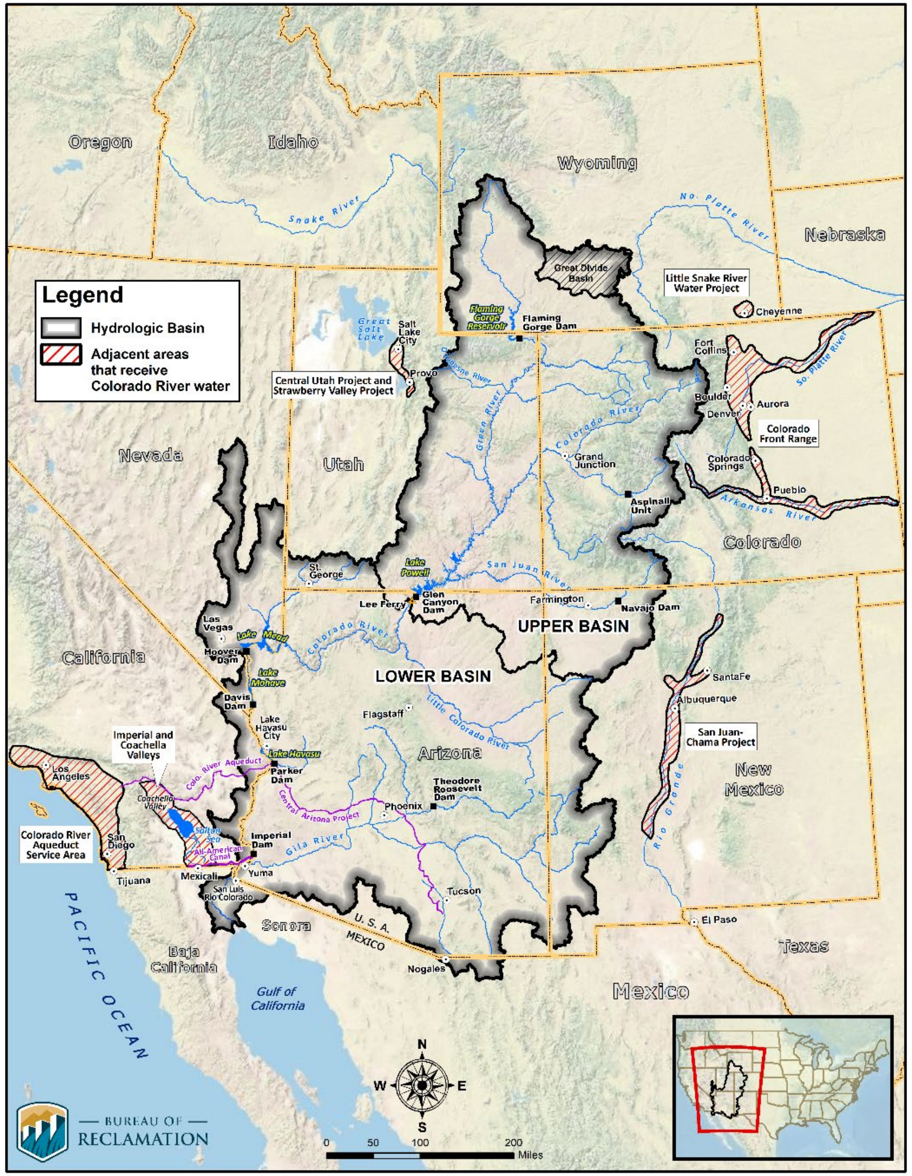
Critical Context for the Post-2026 Web Tool

- User-friendly interface connected to CRSS
  - Create policies that are formatted and sent to CRSS
  - Interact with output from CRSS simulations
- Inclusive
  - No prior experience with CRSS required to explore alternatives
  - 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 exploration
  - Many implementation details of policies will be addressed in later stages of alternative development

CRSS: Background

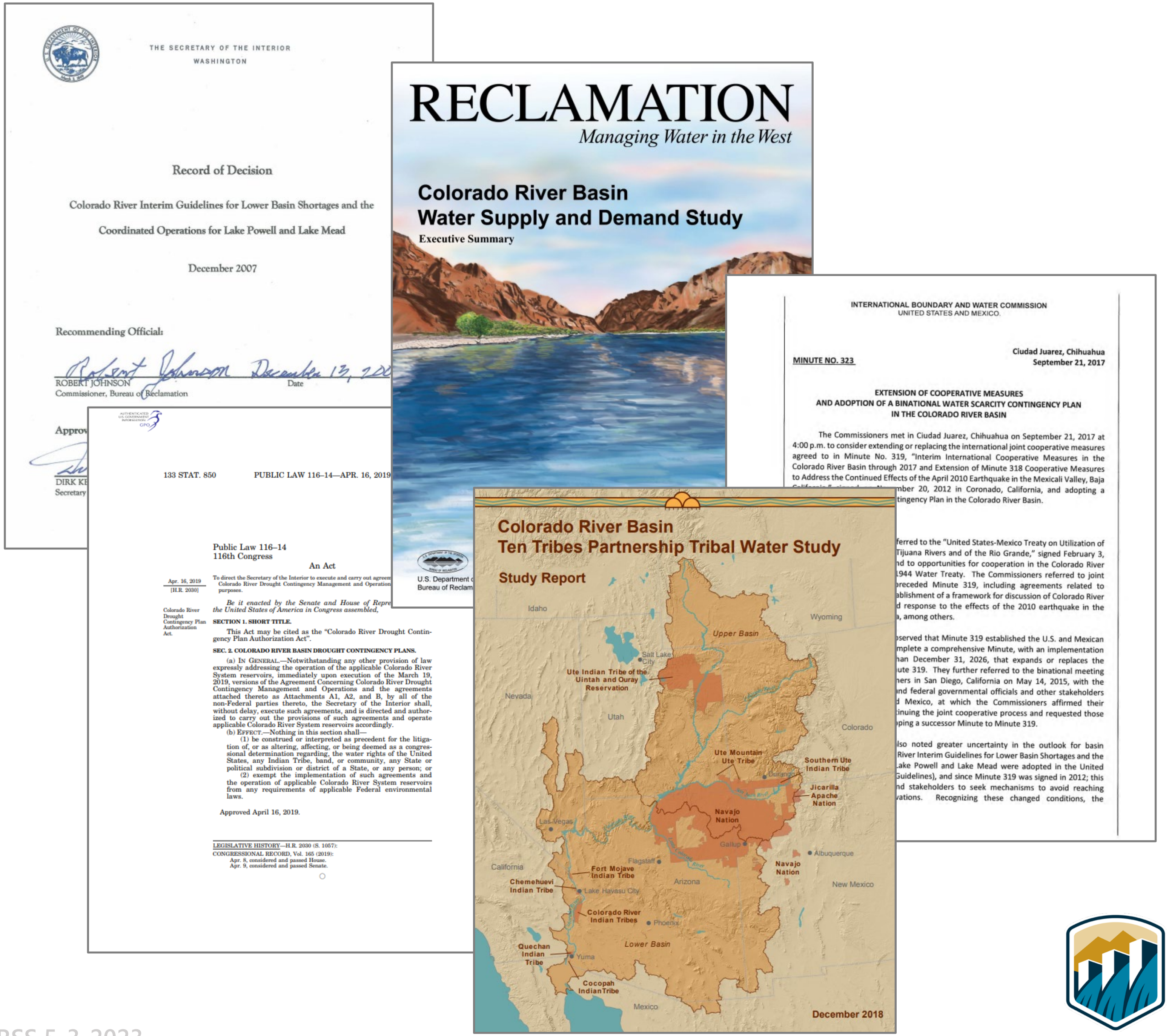
CRSS: A Basin-Wide, Long-Term Planning & Policy Model

- Implemented in RiverWare
- Comprehensive model of the Colorado River Basin
- Primary tool for analyzing future river and reservoir conditions in a long-term planning context
- Generates potential future conditions for many critical system components (e.g., reservoir elevations, releases, energy generation) at a monthly timestep for decades into the future
- Used for "what-if" analyses or ensemble-based probabilistic analyses
- Primary uses
  - Comparative policy analysis
  - Exploring uncertainty
  - Sensitivity analysis



CRSS in Past Planning Efforts

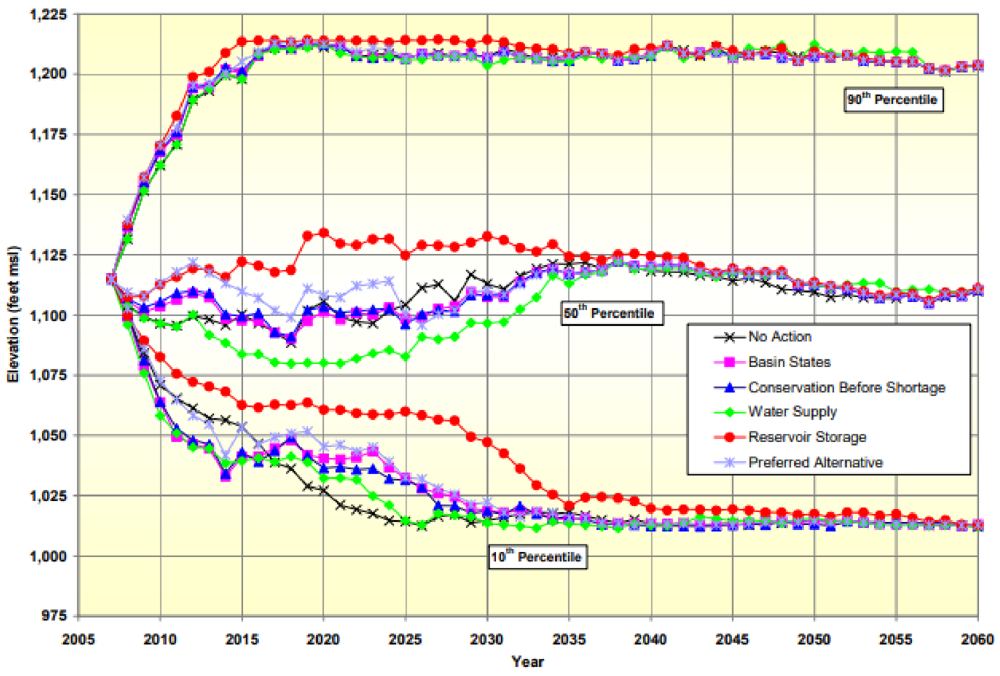
- Interim Surplus Guidelines (2001)
- Multi Species Conservation Program (2005)
- 2007 Interim Guidelines (2007)
- Colorado River Basin Water Supply and Demand Study (2012)
- Minute 319 and 323 to the 1944 Water Treaty (2012 and 2017)
- Ten Tribes Partnership Tribal Water Study (2018)
- Drought Contingency Plans (2019)



Modeling in Past Studies

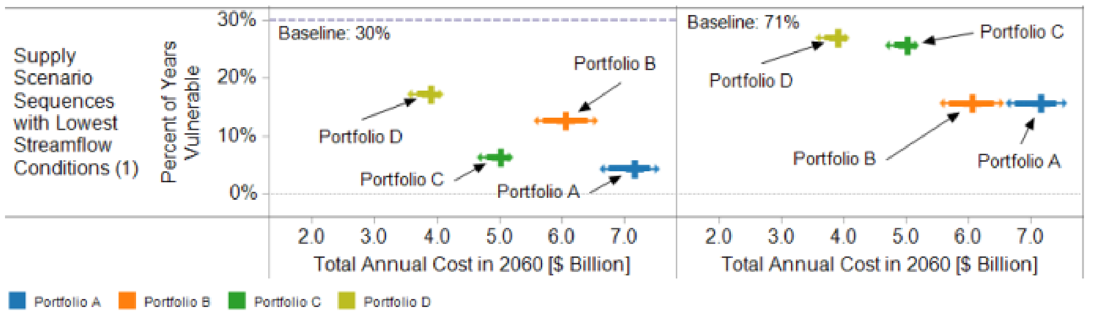
2007 Interim Guidelines (2007)

Figure 4.3-16
Lake Mead End-of-December Elevations
Comparison of Action Alternatives to No Action Alternative
90th, 50th, and 10th Percentile Values



Basin Study (2012)

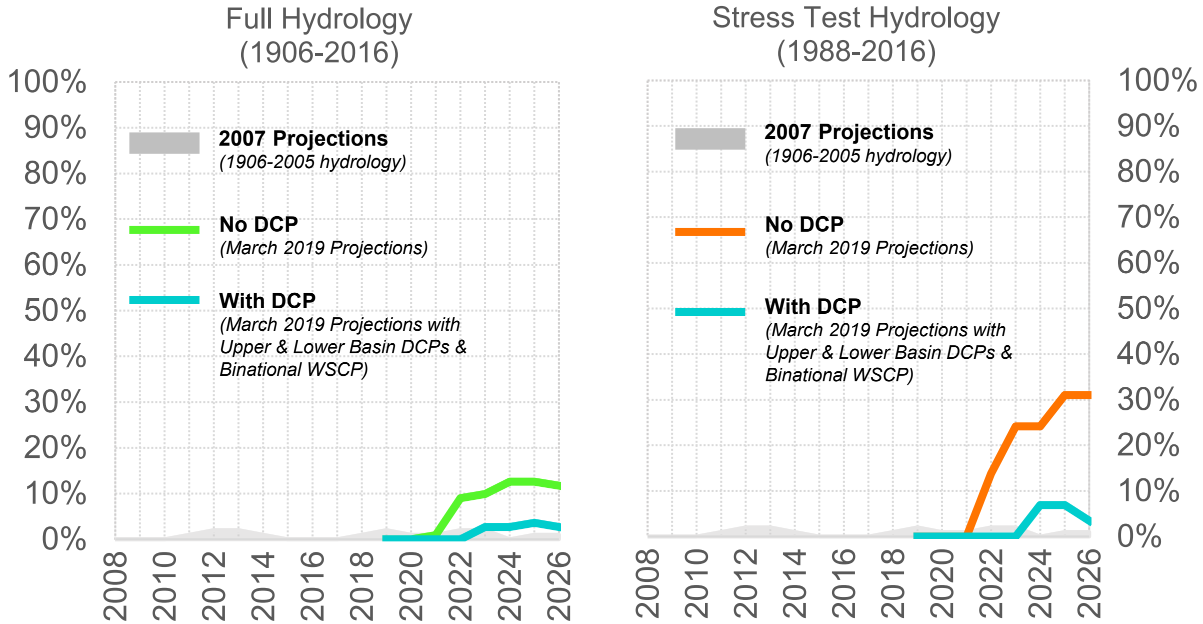
Portfolio Cost and Percent Vulnerability for 2041–2060 for Lowest Sequences



(1) Conditions in which long-term mean natural flows are less than 14 mafy and the 8-year dry period flows are less than 11 mafy.
(2) Marker indicates the 50th percentile result and the bounds represent 25th and 75th percentile results.

Drought Contingency Plans (2019)

Lake Powell < 3,490 Feet in Any Month



CRSS Development and Distribution

- Reclamation maintains and develops the model and provides support and training to interested parties
- Stakeholder involvement
  - Stakeholder modeling workgroup formed in 2010
    - Workgroup members include states, tribes, municipalities, consultants, academics
    - Model and inputs from official runs provided via this group
  - Coordination and technical assistance to Mexico since 2010
- Continually improving
  - Updates to reflect new operations and best available information
  - Improvements in model performance
  - Recently improved representation of Upper Basin, reduced bias, and added calibration capabilities
- Broad stakeholder acceptance

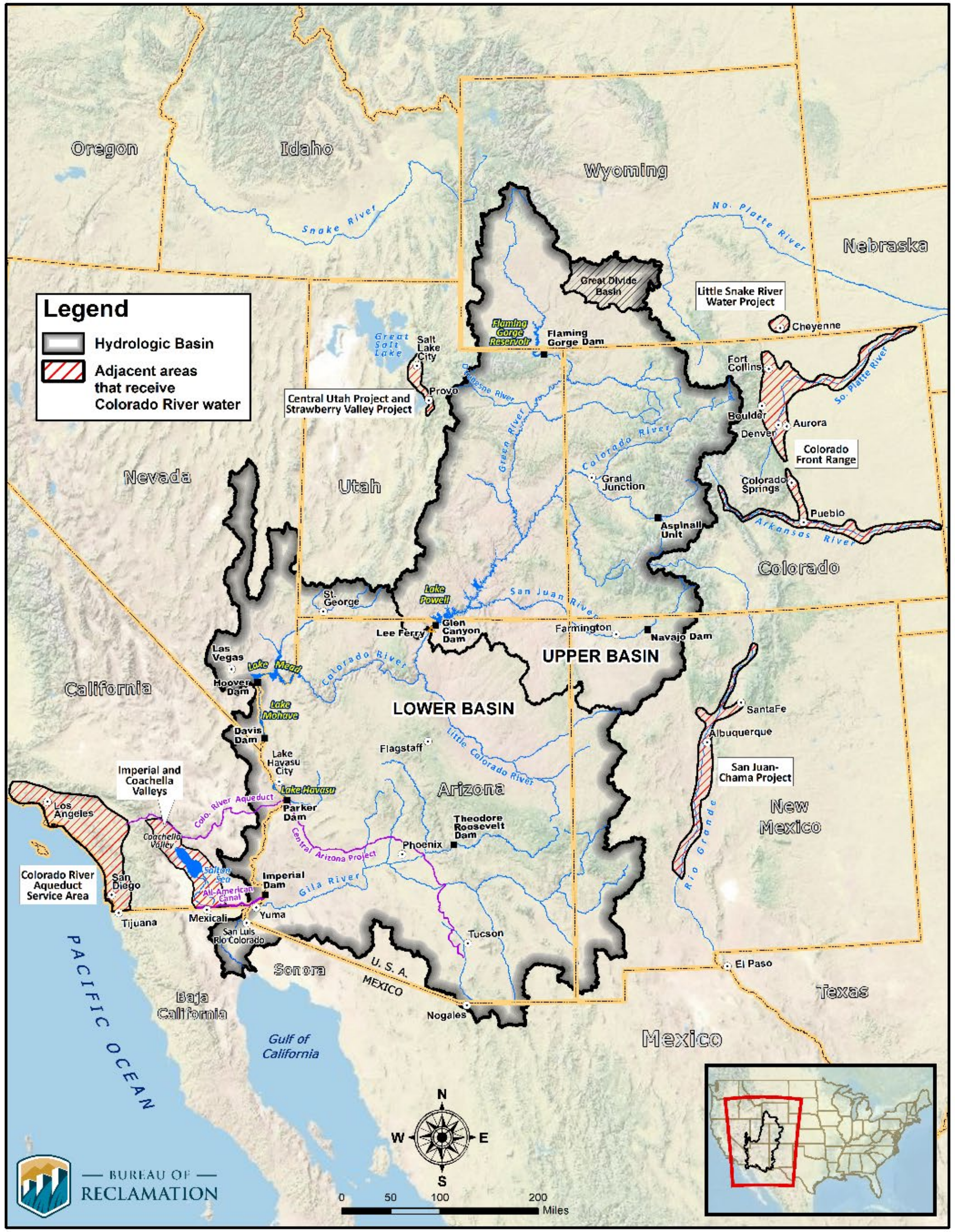
Error in CRSS modeled inflow to Lake Powell

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

Outline of Technical Overview

- Geography and structure
  - Fontenelle down to Northerly International Boundary (NIB)
  - Major tributaries in the Upper Basin
  - Focused on major reservoirs operated by Reclamation
  - Spatially distributed users at varying levels of detail in Upper and Lower Basins
- Inputs
  - Hydrology (supply)
  - Demands
  - Model operating rules (policy)
  - Initial conditions
- Outputs – timeseries and statistics
  - Reservoir levels
  - Water use
  - River flow
  - Energy generation



CRSS: Technical Overview

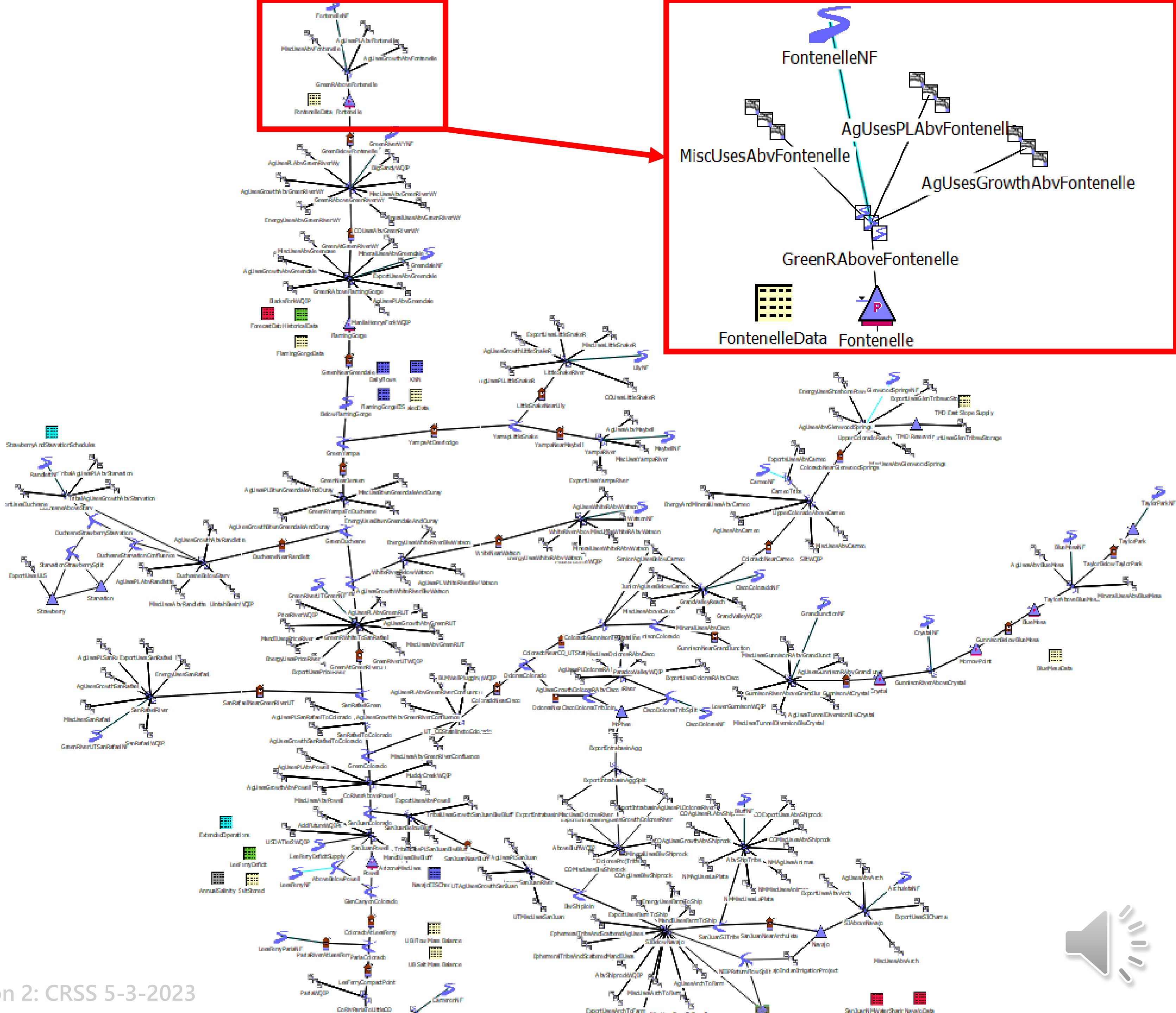
Model Features

- Rivers
  - Upper Basin: Colorado, Green and San Juan Rivers and their major tributaries
  - Lower Basin: Mainstem Colorado and some tributaries
- 15 Major Reservoirs
  - 12 Reclamation operated and 3 operated by partner agencies
- 500+ Water Users
  - Upper Basin: spatial aggregations of many water users
  - Lower Basin: individual mainstem water users

Sourced from Groves, et. al. (2013) Adapting to a Changing Colorado River: Making Future Water Deliveries More Reliable Through Robust Management Strategies

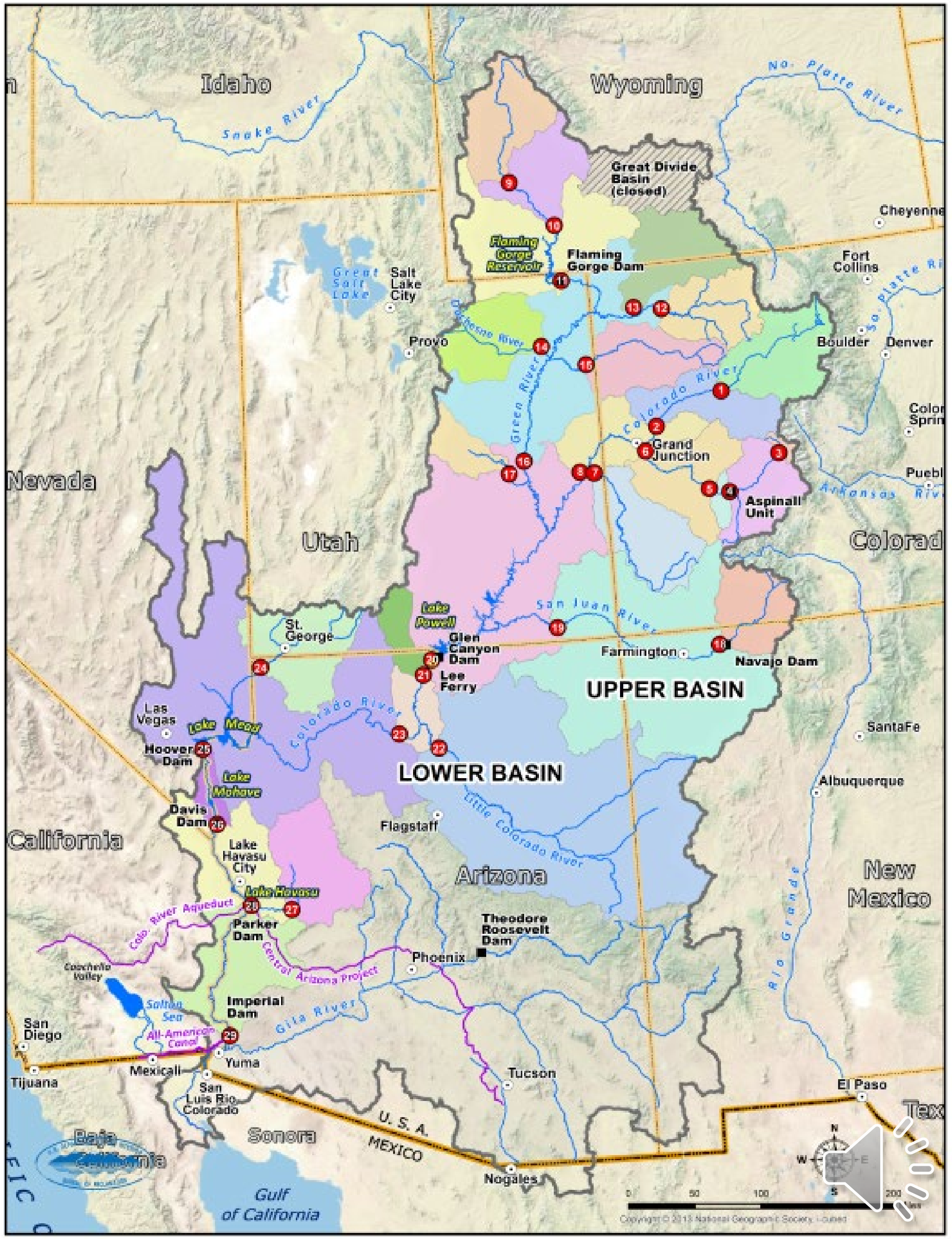
Model Layout

- RiverWare Objects
  - Natural Flow Points
  - Aggregate Water Users
  - Reaches
  - Reservoirs



Hydrology (Supply)

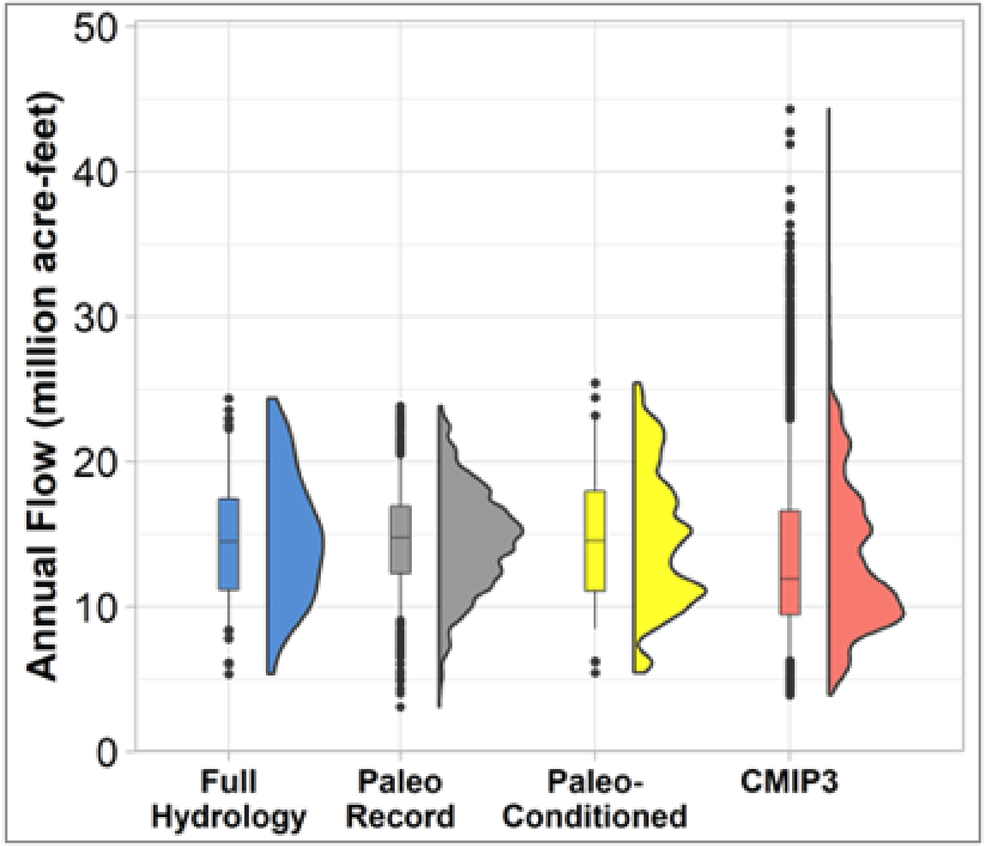
- Natural flow approximates the flow that would have occurred if there were no human influences
  - Reclamation maintains dataset of historical natural flow computed from USGS gages, reservoir regulation, and consumptive uses and losses
  - All hydrologic inputs into CRSS (supply scenarios) are derived from Reclamation's dataset
- Upper Basin: 21 natural flow points
- Lower Basin: 8 inflow points for gaged and intervening flows
- Using natural flow allows CRSS to model potential changes to reservoir operations under varying projections of both supply and demand



Supply Scenarios

- Future inflows are the largest source of uncertainty
  - Results are most sensitive to assumptions about future supply
  - Uncertainty addressed by using multiple timeseries or “traces” of inflow
- Multiple methodologies are used to develop future supply scenarios
  - Observed historical data
  - Tree ring reconstructions
  - Downscaled climate model projections
- Post-2026 will use multiple supply scenarios (covered in a future ITEW session)

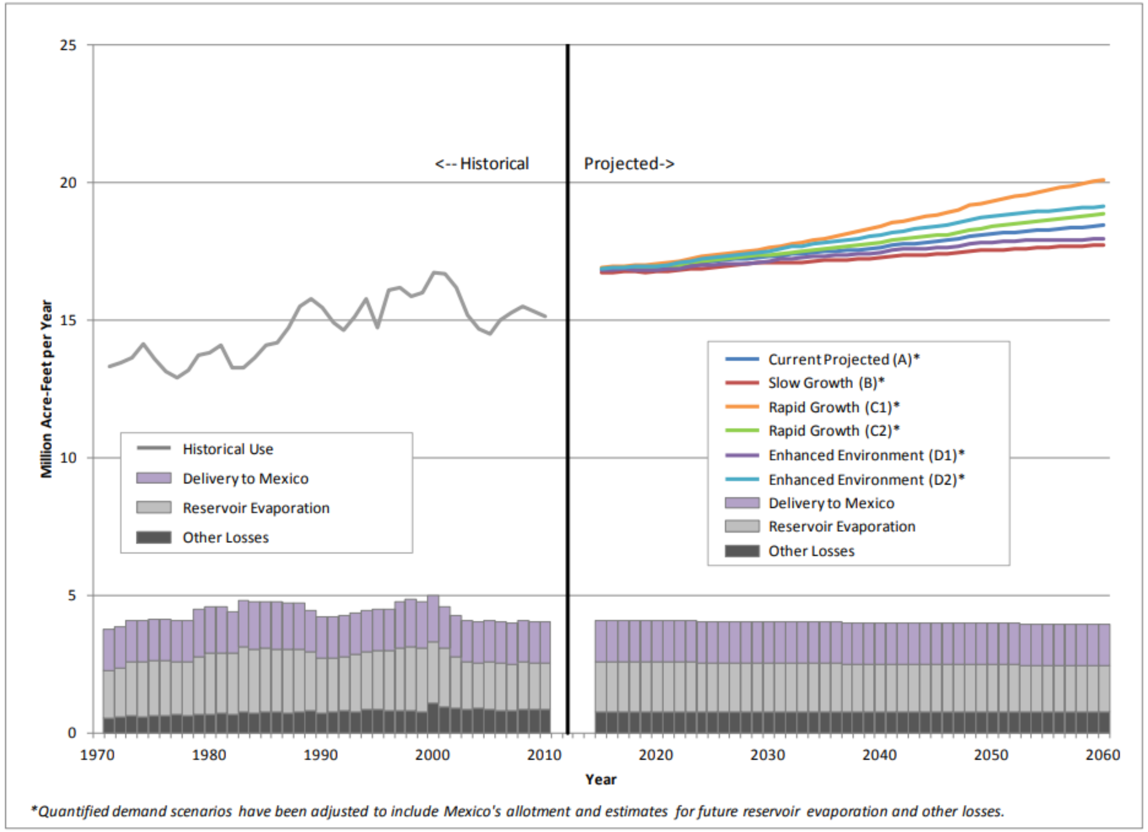
Distributions of Annual Lees Ferry Flow



Demands

- Demands are input, depletions are calculated
  - Demand: water needed to meet identified uses under ideal hydrologic and economic conditions
  - Depletion: consumptive use
- Water user sectors include agricultural, M&I, tribal, exports, etc.
- Upper Basin
  - Upper Colorado River Commission (UCRC) demand schedule
  - Water users shorted based on water availability and calibration
  - Tribal demands are based on the Tribal Water Study
- Lower Basin
  - Water use assumptions developed in coordination with Lower Division States and Mexico
  - Water user delivery reductions and increases determined by operations
- Post-2026 will use multiple demand scenarios to address uncertainty associated with future demand (covered in a future ITEW session)

Basin-wide Historical Use and Projected Future Demands, etc.



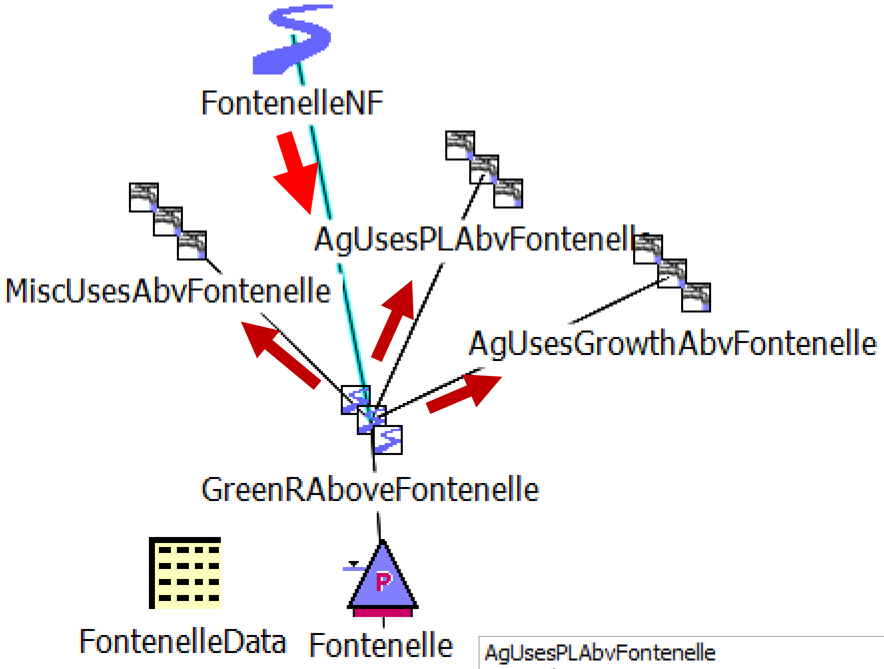
Source: 2012 Basin Study Technical Report C

Example: Supply & Demand above Fontenelle

- Natural flow and water user demand are input
- Water users divert water based on available supply
- Water is consumed or "depleted"

FontenelleNF .Inflow acre-ft/month

23,887	I	0
17,731	I	0
45,958	I	0
65,408	I	0
230,610	I	0
340,312	I	0



AgUsesPLAbvFontenelle :Agriculture .Depletion Schedule acre-ft/month

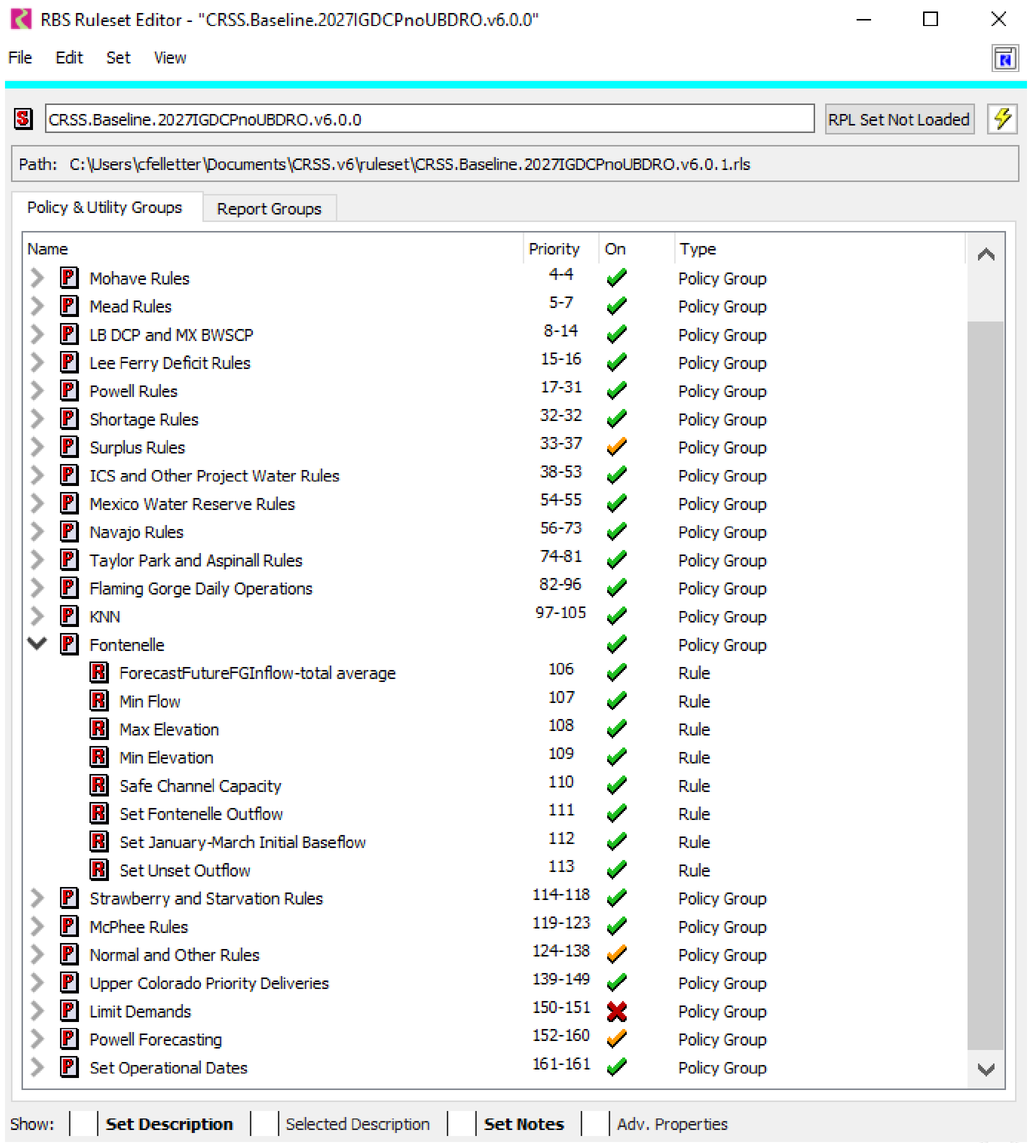
30,278	I	0
91,416	I	0
134,911	I	0
57,087	I	0

AgUsesPLAbvFontenelle .Total Depletion acre-ft/month

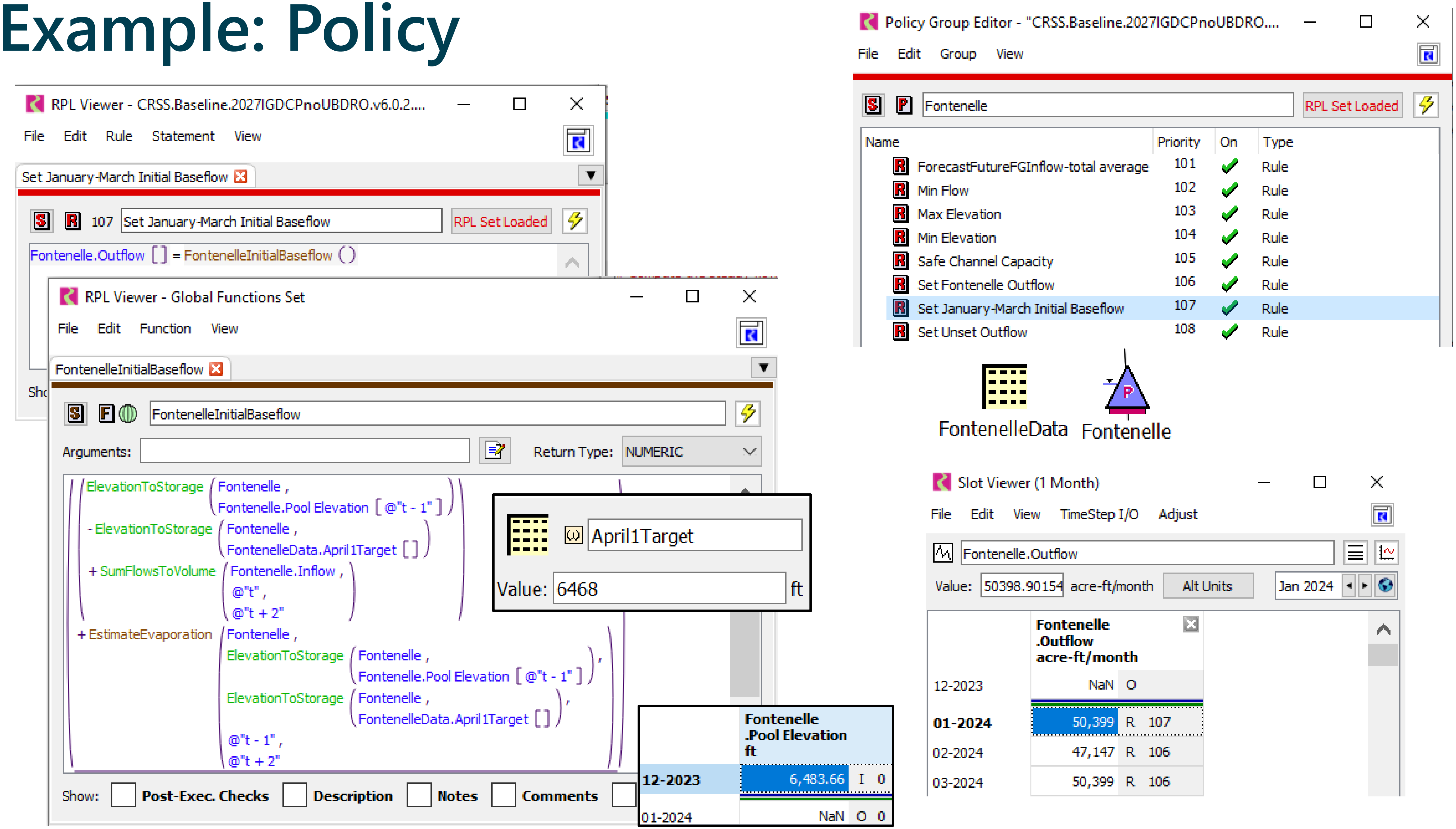
9,092.79	O	137
35,089.69	O	137
21,686.98	O	137
8,762.39	O	13[illegible]

Operating Rules

- Reservoir operations and water deliveries are approximated using “rules” in the model
  - Rules and functions provide necessary logic (e.g., IF statements) that, along with other user input, allow the model to complete a simulation
  - Collectively the rules and functions make up a “ruleset” that governs the simulation
  - The ruleset mimics how the system would be operated
- 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
- Post-2026 will explore multiple operational policies (covered in future ITEW session)

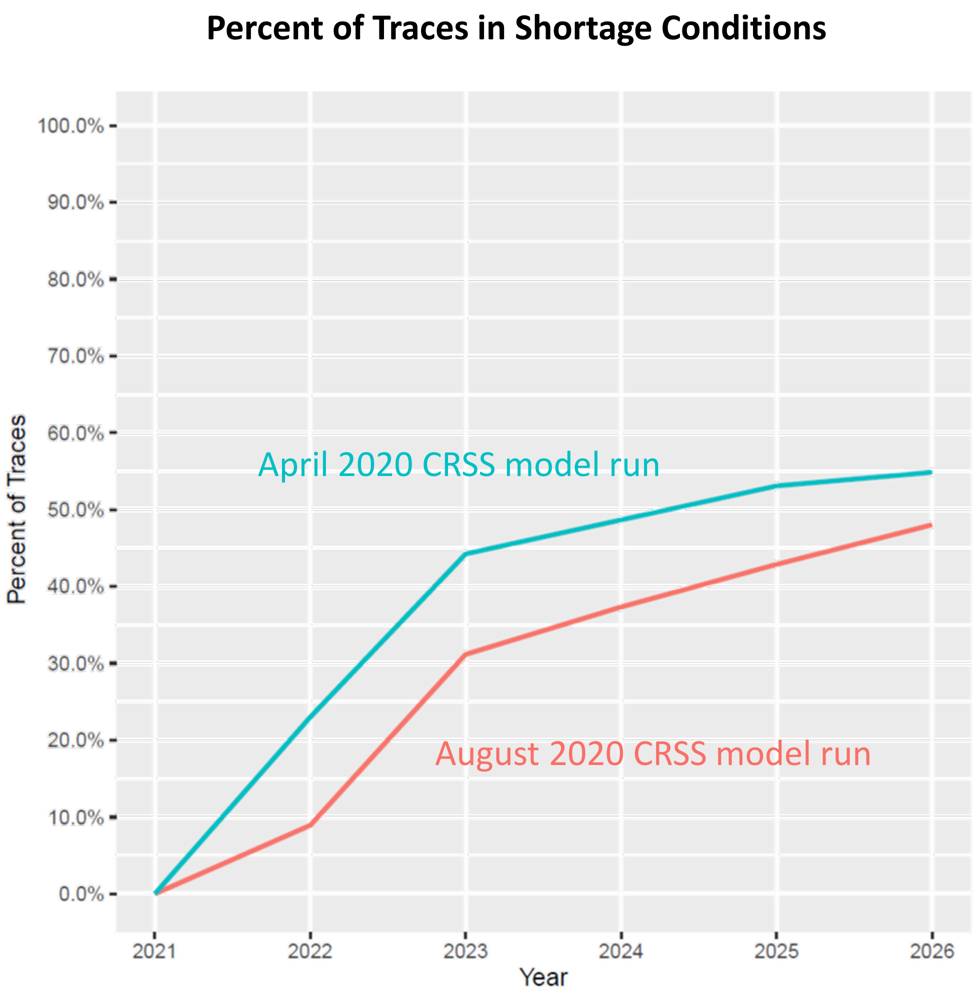


Example: Policy



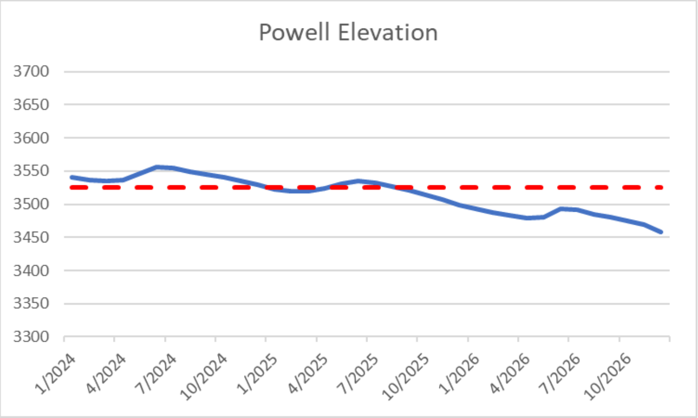
Initial Conditions

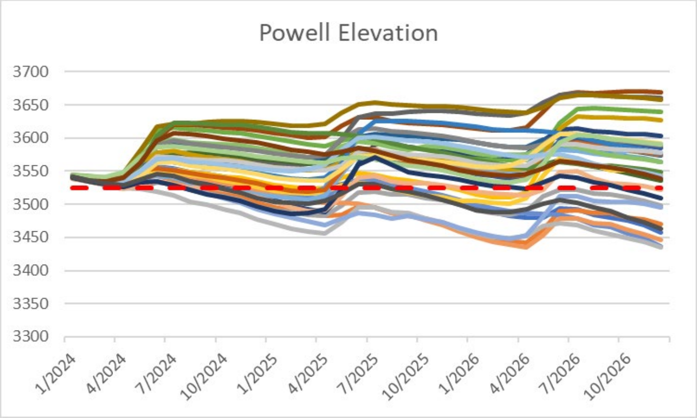
- CRSS requires initial reservoir elevations and other system conditions
- Initial conditions have a large impact on the range of potential system conditions in the first 5-10 years of a simulation, especially at Lake Powell and Lake Mead
- Since the condition of the system in 2027 will be uncertain, Post-2026 will use multiple sets of initial conditions during the screening phase of alternatives development

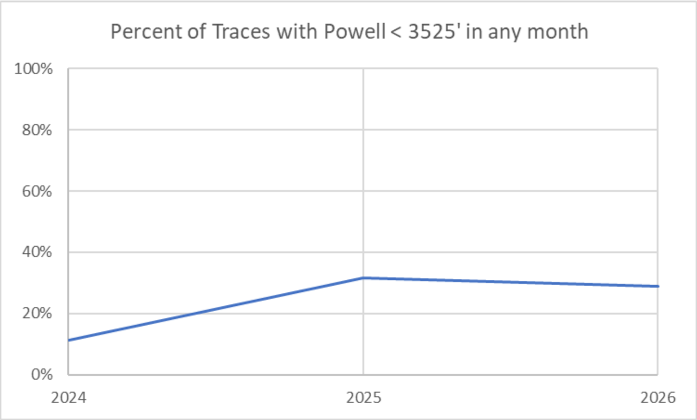


Common CRSS Output

- Monthly and annual output
  - Individual trace (simulation) values
  - Statistics across all traces in scenario(s)
- Releases, elevations, energy production, etc., at 12 UB and 3 LB reservoirs
  - Average monthly release, end-of-month elevation
- Monthly flow at 31 gages in the Basin
  - Can provide stage, using USGS stage-flow curves
  - Also can provide daily approximations at certain gages in model
- Consumptive use
  - By state, basin, and sub-basin
  - By user in Lower Basin
  - With caveats; more info in future ITEW session







Model Limitations

- Estimates of river flow are only meaningful at specific gages and reservoirs due to the spatial aggregation of demands and lumped nature of natural flow input
- Limited representation of Upper Basin water rights
  - Water is not assigned or tracked; demands are met in specific locations based on water availability
  - No water accounting or shepherding
- Limited representation of Lower Basin tributaries
  - Modeled tributaries are based on gaged flows and do not explicitly model water use
- Monthly timestep, not daily
  - Impacts what types of resources can be modeled
  - Can be coupled with other models to provide daily estimates
- Flow-based modeling only, no representation of temperature, sediment, etc.
- Assumptions must be made about processes that are difficult to model, and these can impact results
  - Adaptive management and operational flexibility
  - Water use patterns, etc.
  - Low reservoir levels where operating experience is limited

Policy Modeling Demo

Modeling a New Policy

- What is required to model a "new policy"?
- Policy has to be model-able
  - Ideas must be relevant to specific reservoir operations, water user behavior, river flows, etc.
  - Ideas must be able to be expressed using model rules and numbers that work within the structure of CRSS
- If model-able, changes are made in the model that lead the reservoirs to operate differently. Depending on the scope of the change from current policy, it may require
  - Changing specific values
  - Altering existing rules
  - Developing new rules
- **For demonstration purposes only**, we will model a "new policy" where the 2007 Interim Guidelines continue beyond 2026 and DCP expires after 2026

[Demo]

Demo summary

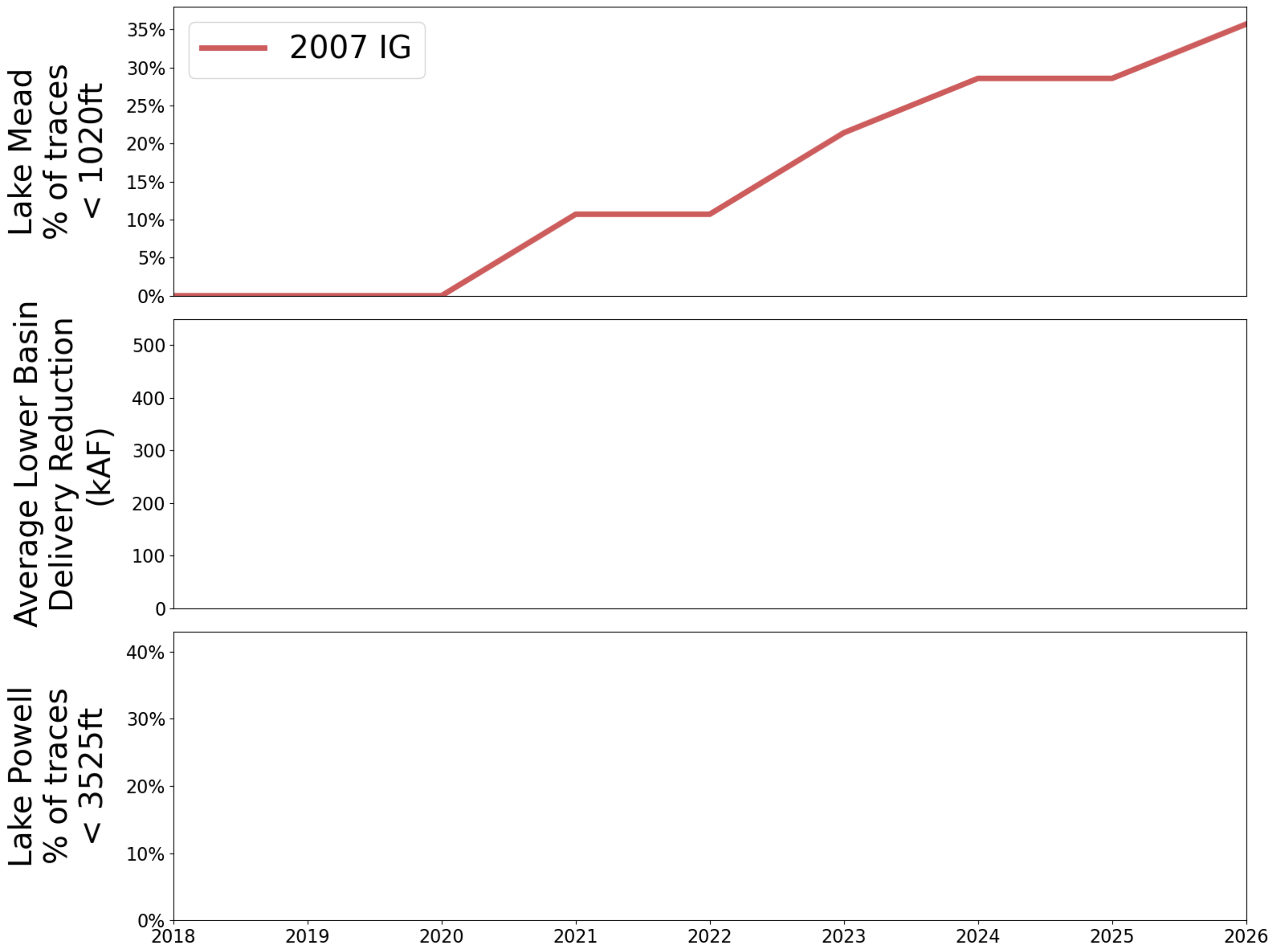
- We showed a simplistic way to change policy and how it affected output
- Post-2026 operational alternatives may be more complex than the example
- To explore a new policy in CRSS, the ideas must be model-able
- The web tool will include multiple complex alternative operational strategies and the functionality to make changes through a user-friendly interface (i.e., you can use CRSS without opening CRSS)

Policy Comparison

Evaluating and Comparing Policies

- Policies are primarily evaluated based on "performance", which can be defined in many ways, some of which are not readily modeled or measured
- Metric = a *quantitative* measure of performance calculated using modeling output (either from CRSS or other models that build on CRSS output)
- Metrics will be critical during all phases of the Post-2026 process, including
  - Alternatives development
  - Impact analysis in the EIS
- Example metrics
  - Percent of traces falling below 3,525 ft at Lake Powell in a given year
  - Average annual energy production at Glen Canyon Dam
  - Average annual flow through the Grand Canyon
  - Percent of traces falling below 1,020 ft at Lake Mead in a given year
  - Average annual Lower Basin delivery reductions
  - Average annual energy production at Hoover Dam

Comparing Policies Using Metrics



Output from October 2017 CRSS modeling

Example metrics

- Percent of traces falling below 3,525 ft at Lake Powell
- Average annual energy production at Glen Canyon Dam
- Average annual flow through the Grand Canyon
- Percent of traces falling below 1,020 ft at Lake Mead
- Average annual Lower Basin shortage volume
- Average annual energy production at Hoover Dam

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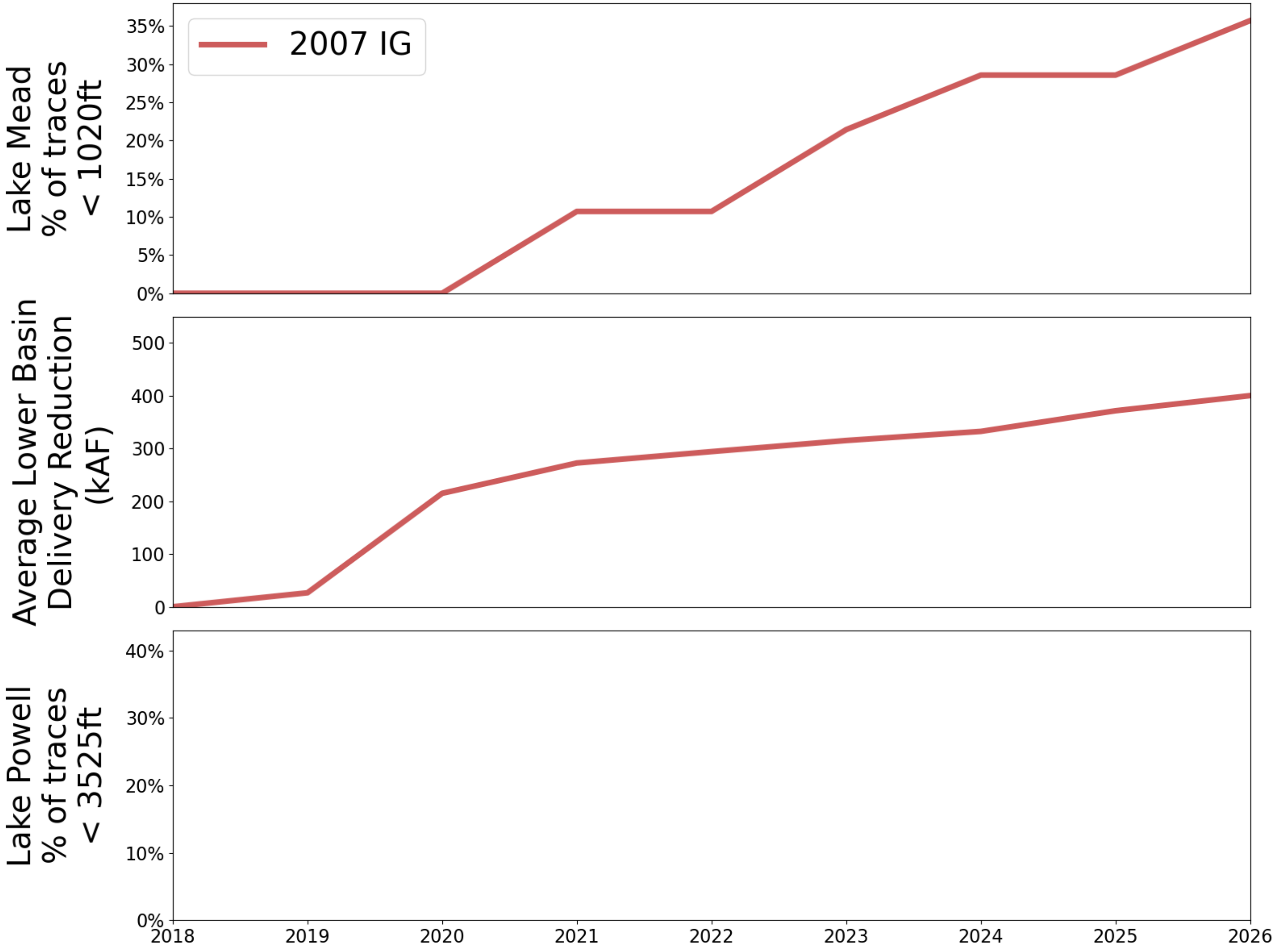

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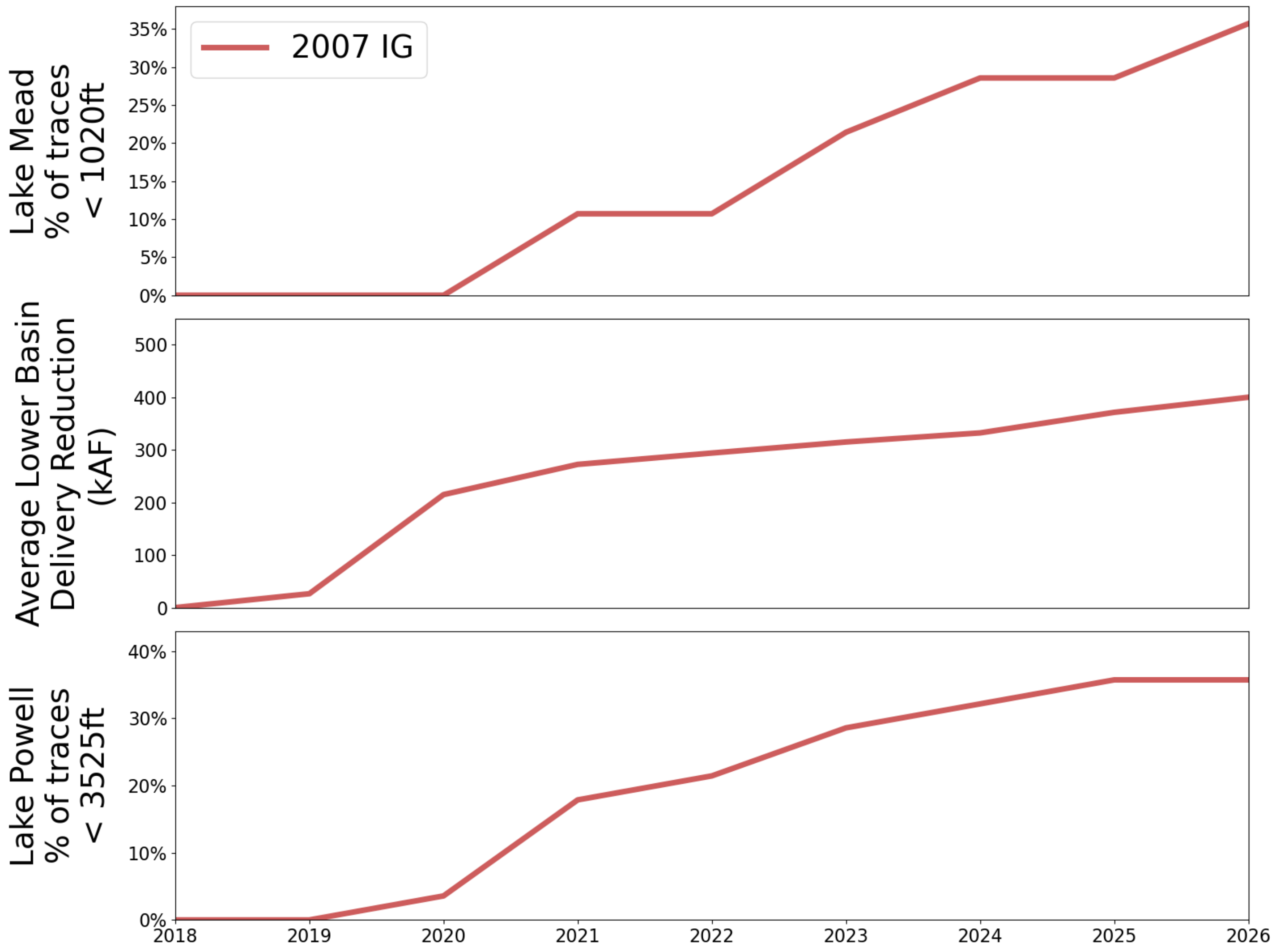

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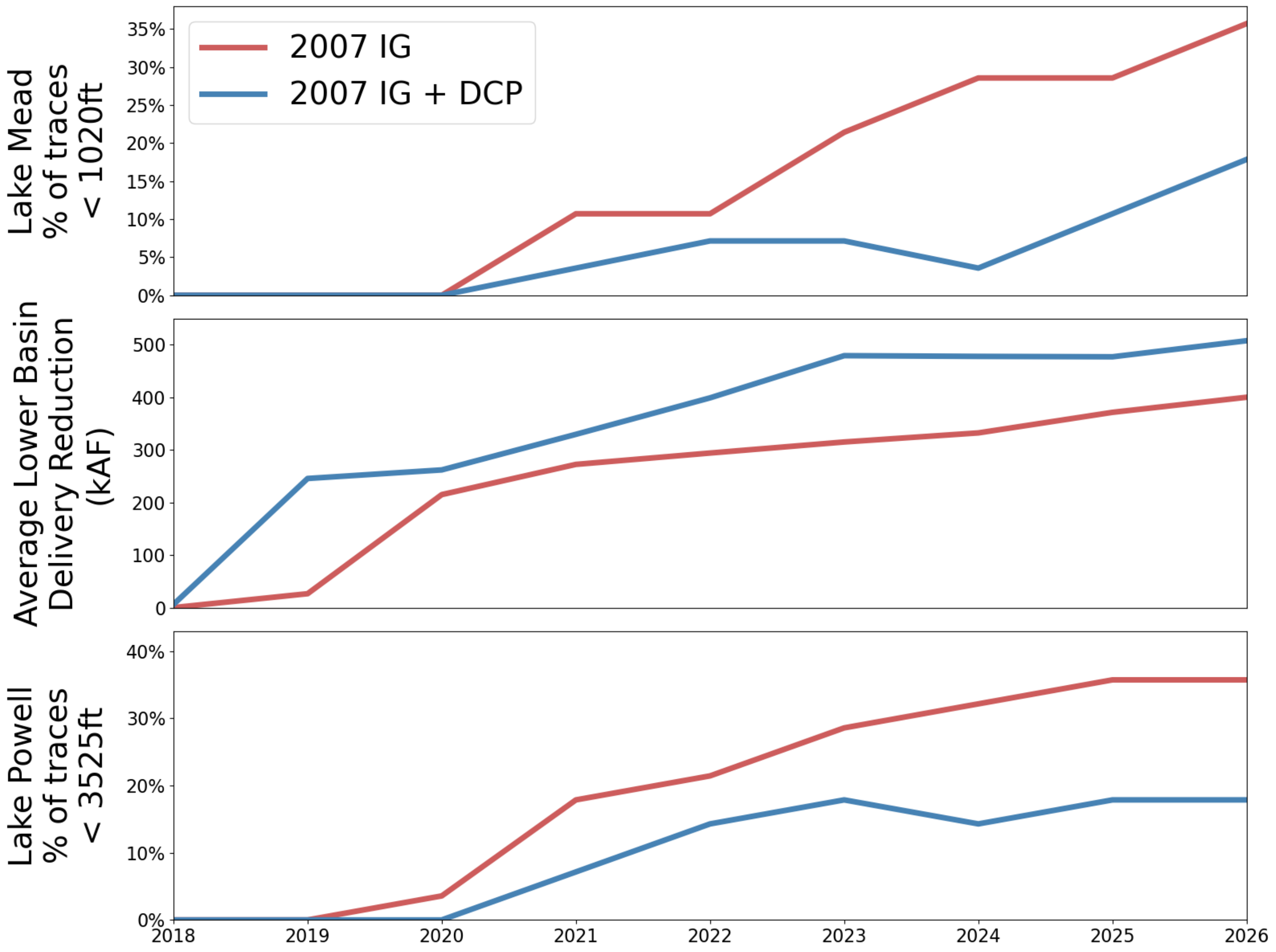
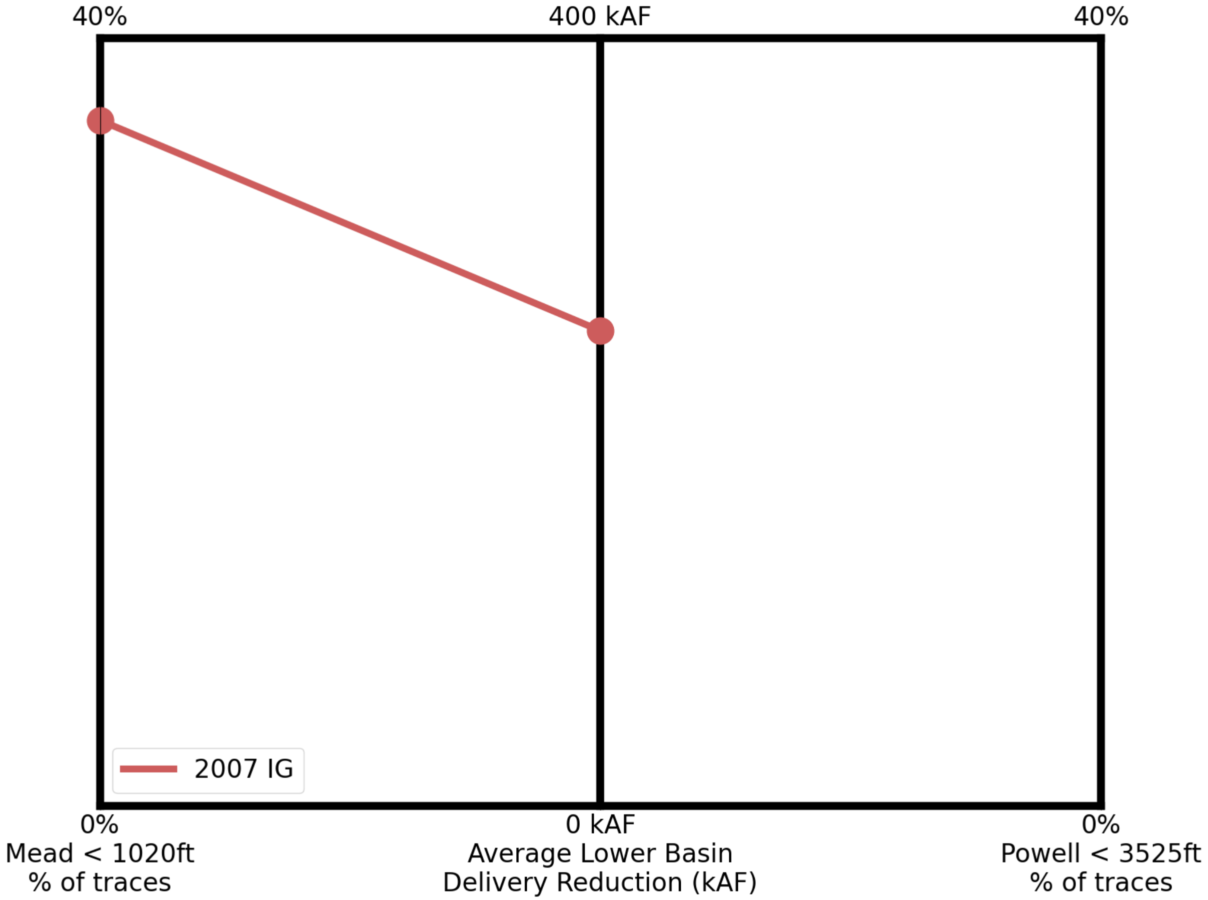


Output from October 2017 CRSS modeling

- Metrics will be critical during all phases of the Post-2026 process, including
  - Alternatives development
  - Impact analysis in the EIS
- Metrics enable consistent, quantitative comparison between policies

Identifying Tradeoffs between Policies



Metrics can be simplified from timeseries to individual values to make comparisons easier

Identifying Tradeoffs between Policies

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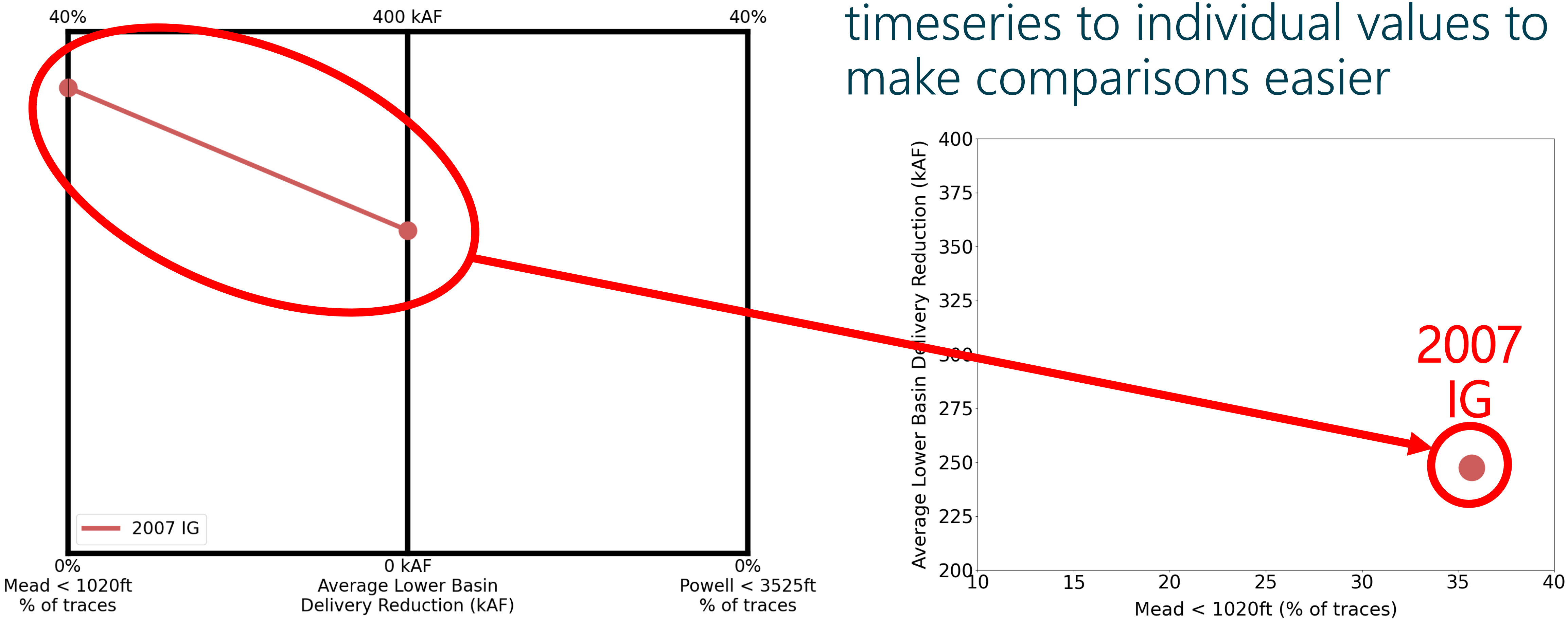

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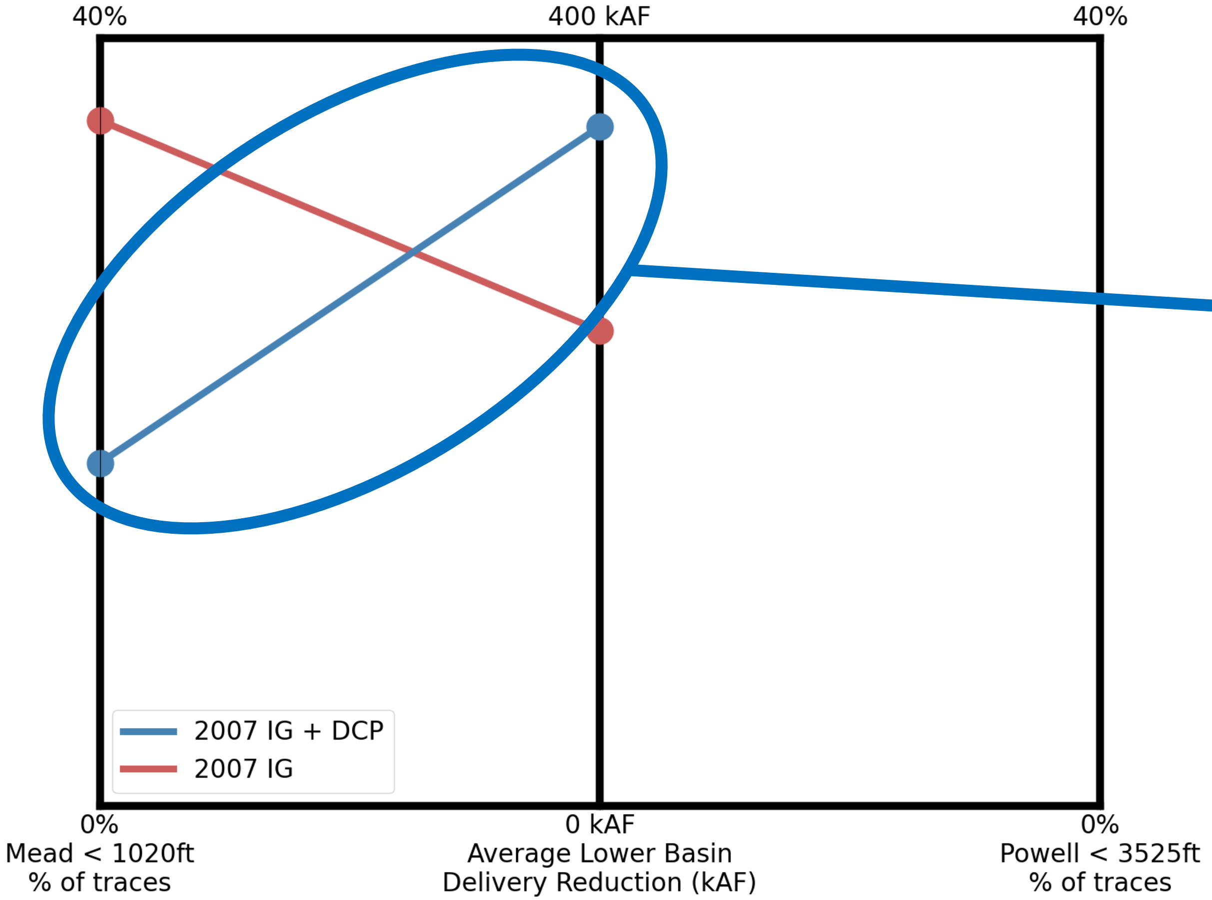

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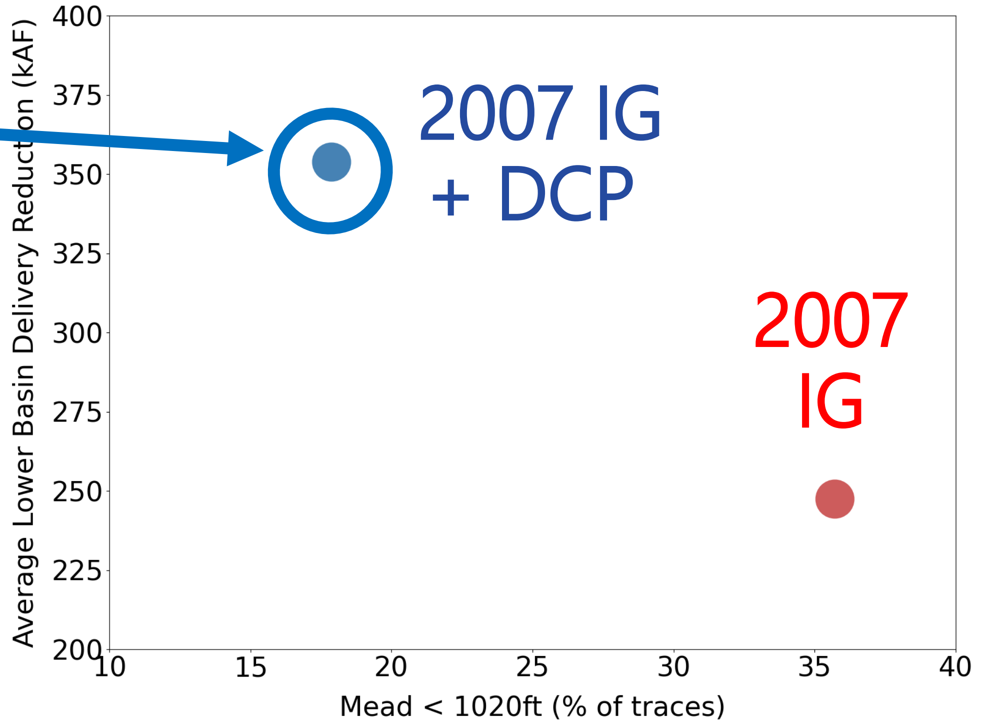
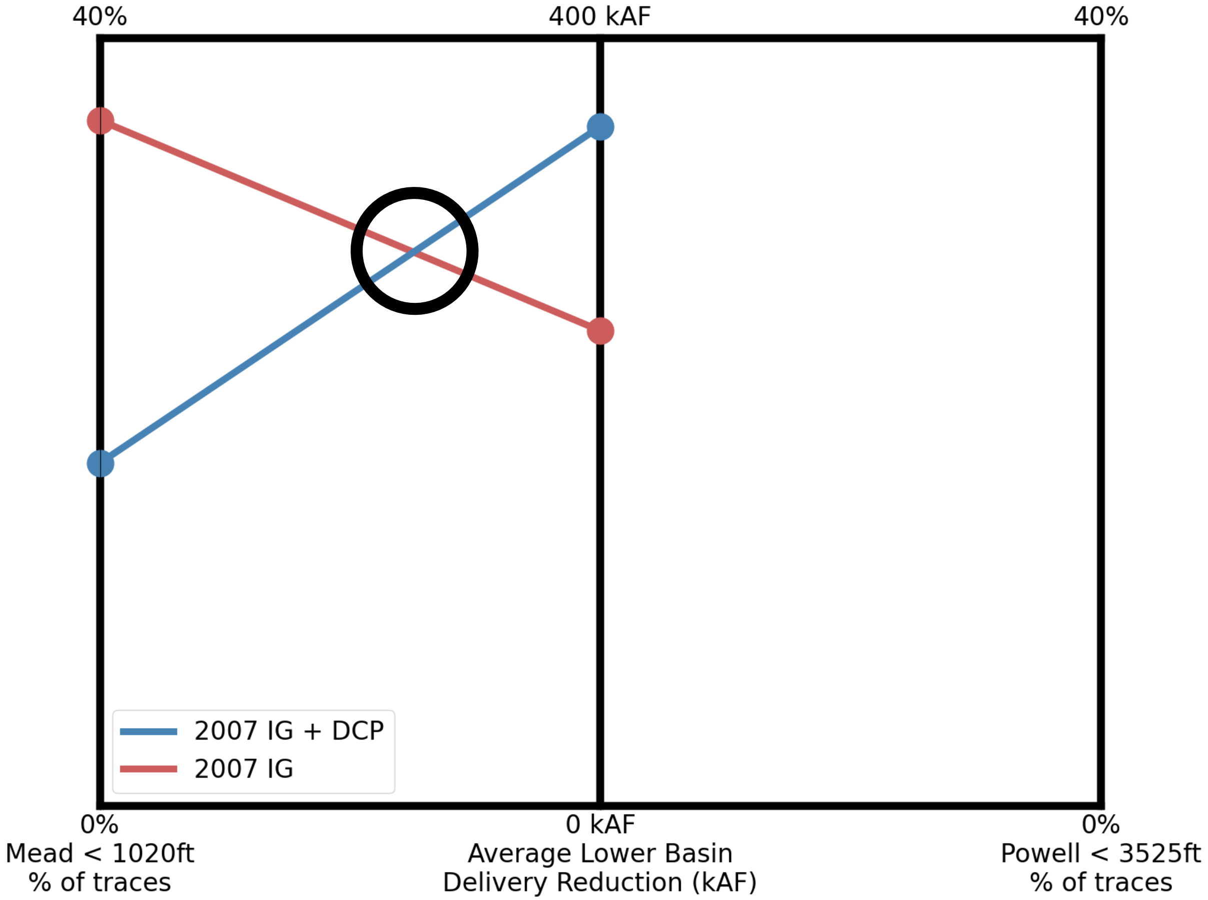
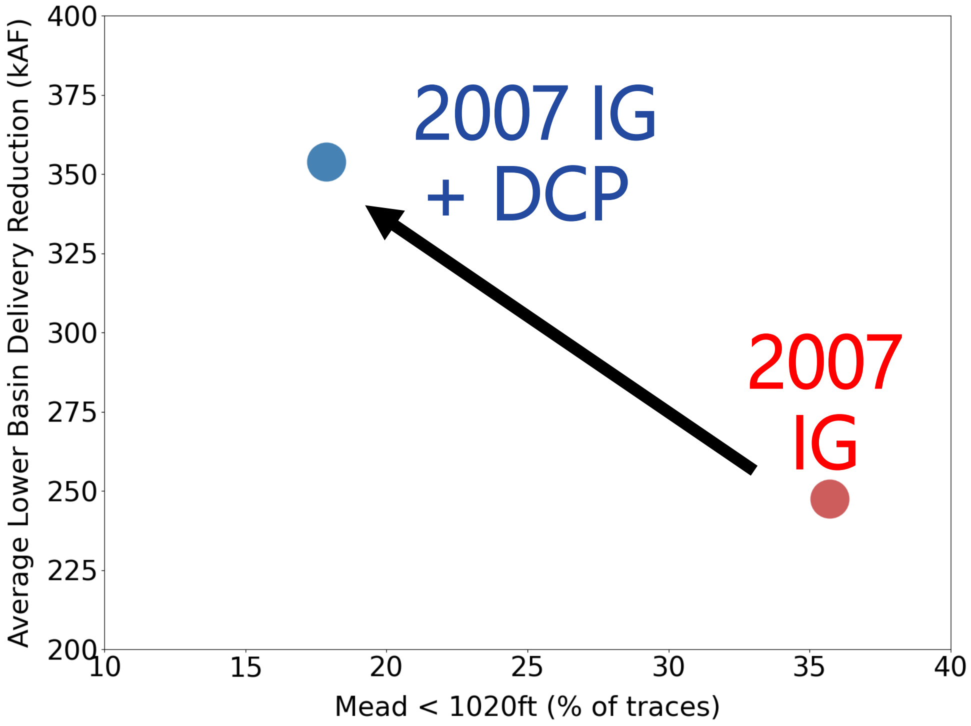


Identifying Tradeoffs between Policies



Intersecting lines represent the tradeoffs of replacing one policy with another



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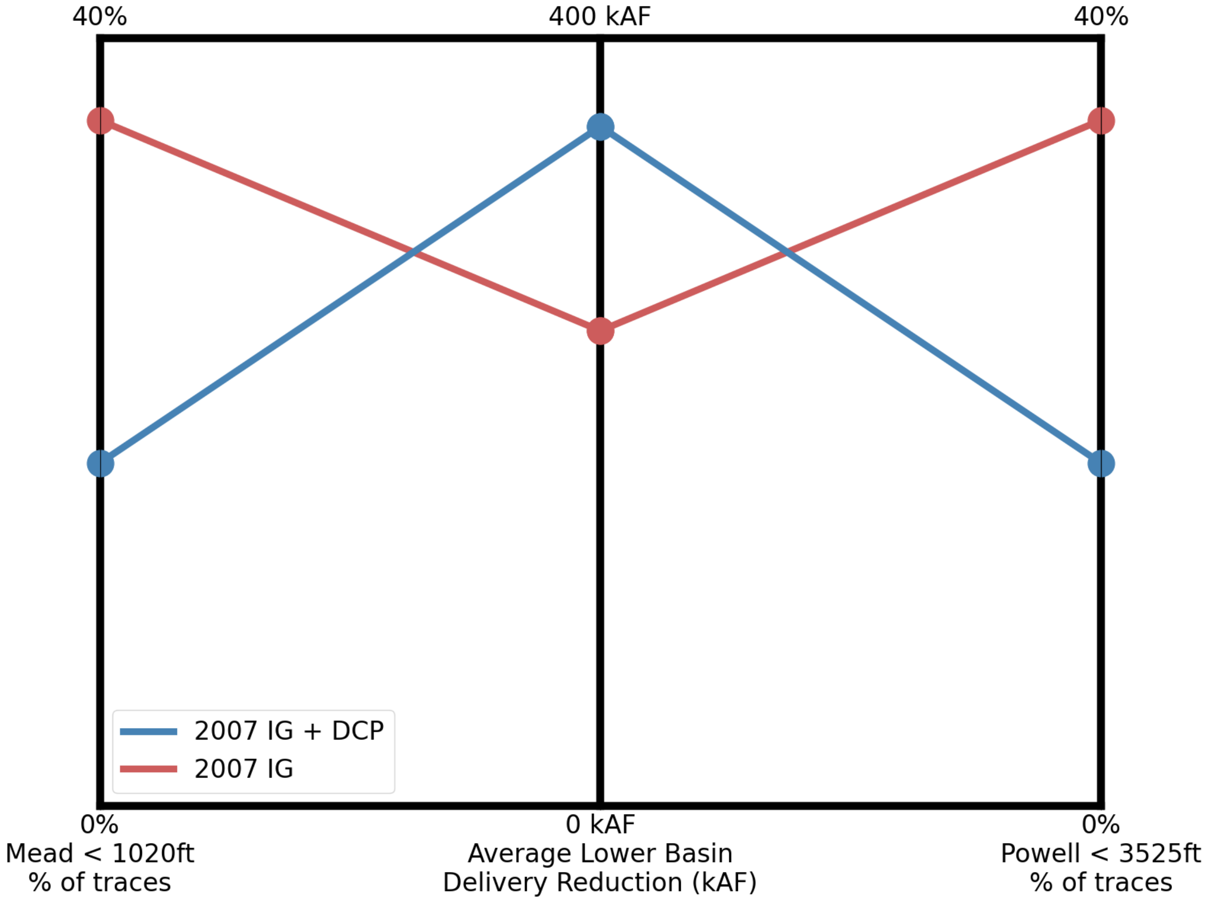
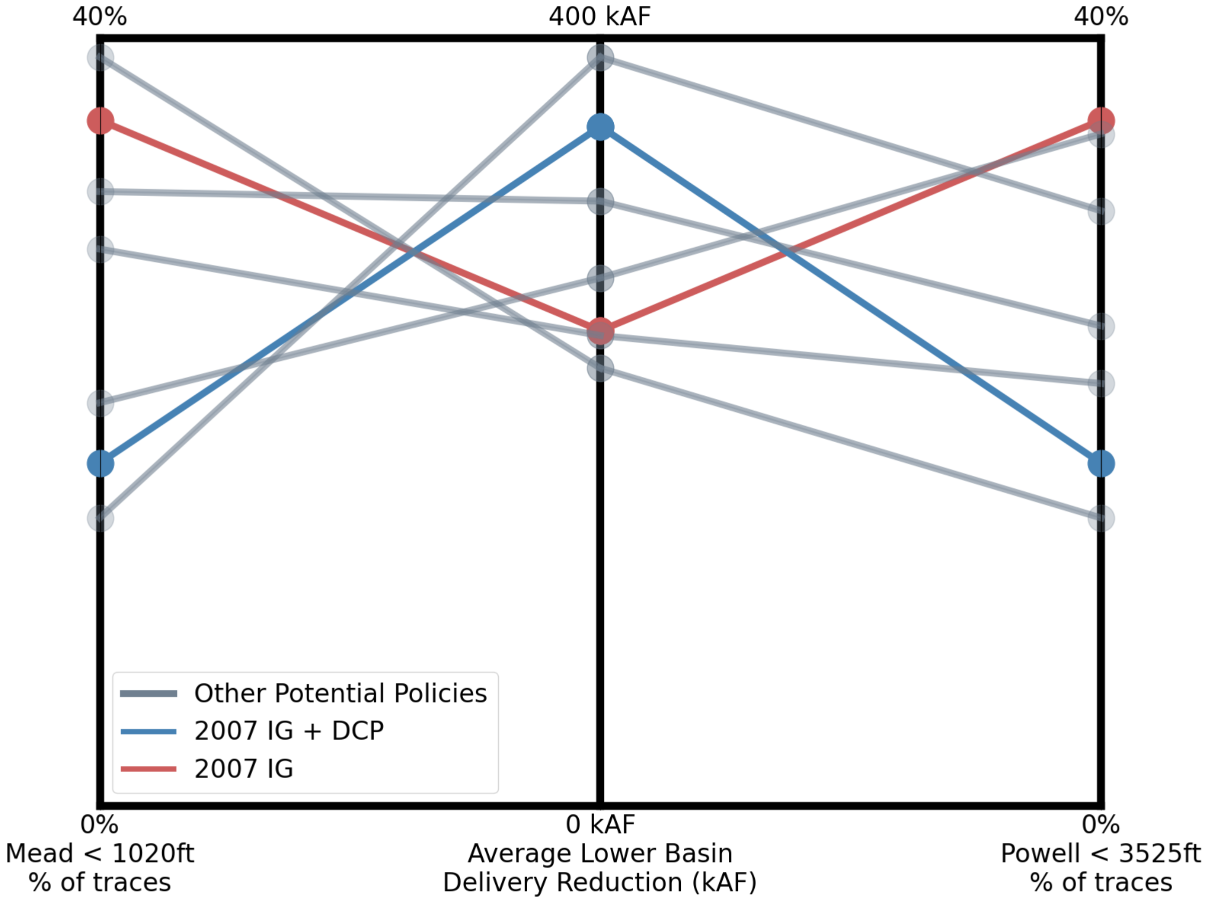


- Intersecting lines represent the tradeoffs of replacing one policy with another
- As we increase the number of objectives we use to evaluate policies, tradeoffs between those objectives become more complicated

Identifying Tradeoffs between Policies



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Session Summary

- CRSS is the primary model that will be used to develop and evaluate operational alternatives in the Post-2026 process
  - In some cases, other models will be used with CRSS output to augment CRSS capabilities
- To explore and compare operational alternatives in CRSS, ideas must be model-able
- Comparing policies using quantitative metrics will play a critical role in all phases of Post-2026 policy development
- The Post-2026 Web Tool will provide a user-friendly interface connected to CRSS that supports the ability to create and analyze policies without opening CRSS *(note- CRSS experience NOT required to use Web Tool)*

Closing

Future Sessions and Request for Input

- Future ITEW session topics include (order TBD)
  - Hydrology
  - Demands
  - Metrics, tradeoffs, robustness and vulnerability
  - Alternative operational strategies (what is available in Web tool, how to explore those that are not)
  - Web tool intro and training
- Content will include general education and information related to the Post-2026 Technical Framework
- Future sessions
  - Late June
  - Late July
  - Early September
  - Early October
  - Early November
- Please send questions, feedback, and requests for topics to bor-sha-crbpost2026@usbr.gov

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
- Colorado River Basin Water Supply and Demand Study: https://www.usbr.gov/lc/region/programs/crbstudy/finalreport/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


Thank You
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RECLAMATION