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Using RiverWare and Decision Making Under Deep Uncertainty Analyses to Support the Colorado River Basin Post-2026 Final EIS

RiverWare User Group Meeting – August 26, 2026

U.S. Bureau of Reclamation, Colorado River Research & Modeling Team

Presenters: Logan Callihan, Sarah Baker, Nathan Bonham

Post-2026 Analytical Challenge: Planning for an Unpredictable Future

Deep Uncertainty

Future Planning Assumptions

Hydrology · Demand · Growth · Water Use

+

Competing Objectives

Resources · Interests · Priorities

+

System Representation

Evolving Analytical Questions

From

How often does an outcome occur?

Example: How often does an operating alternative fail to meet a performance goal, such as Lake Powell falling below elevation 3,490 ft in any month?

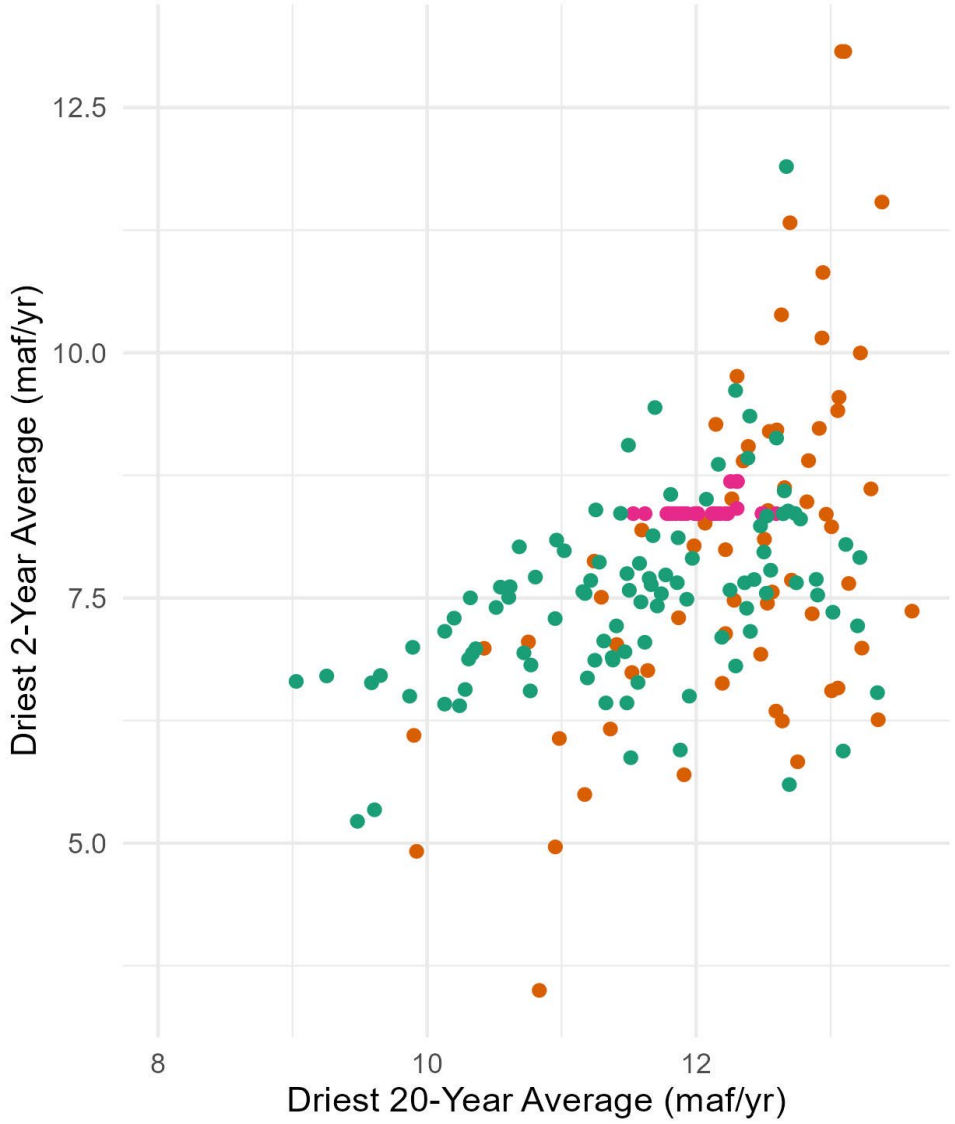
To

Under what conditions does an outcome occur?

Example: Under what hydrologic conditions does an operating alternative fail to meet a performance goal, such as what hydrology causes Lake Powell to fall below elevation 3,490 ft?

The model is familiar. The analytical questions and approach have evolved.

Capturing a Range of Future Hydrologic Conditions



Representing a wider range of plausible hydrologic conditions provides the foundation for answering these evolving analytical questions.

200 TRACES

- Stress Test (36)
- CMIP5-LOCA (64)
- Drying with Variability (100)

See Final Environmental Impact Statement (EIS) Appendix F for more information.

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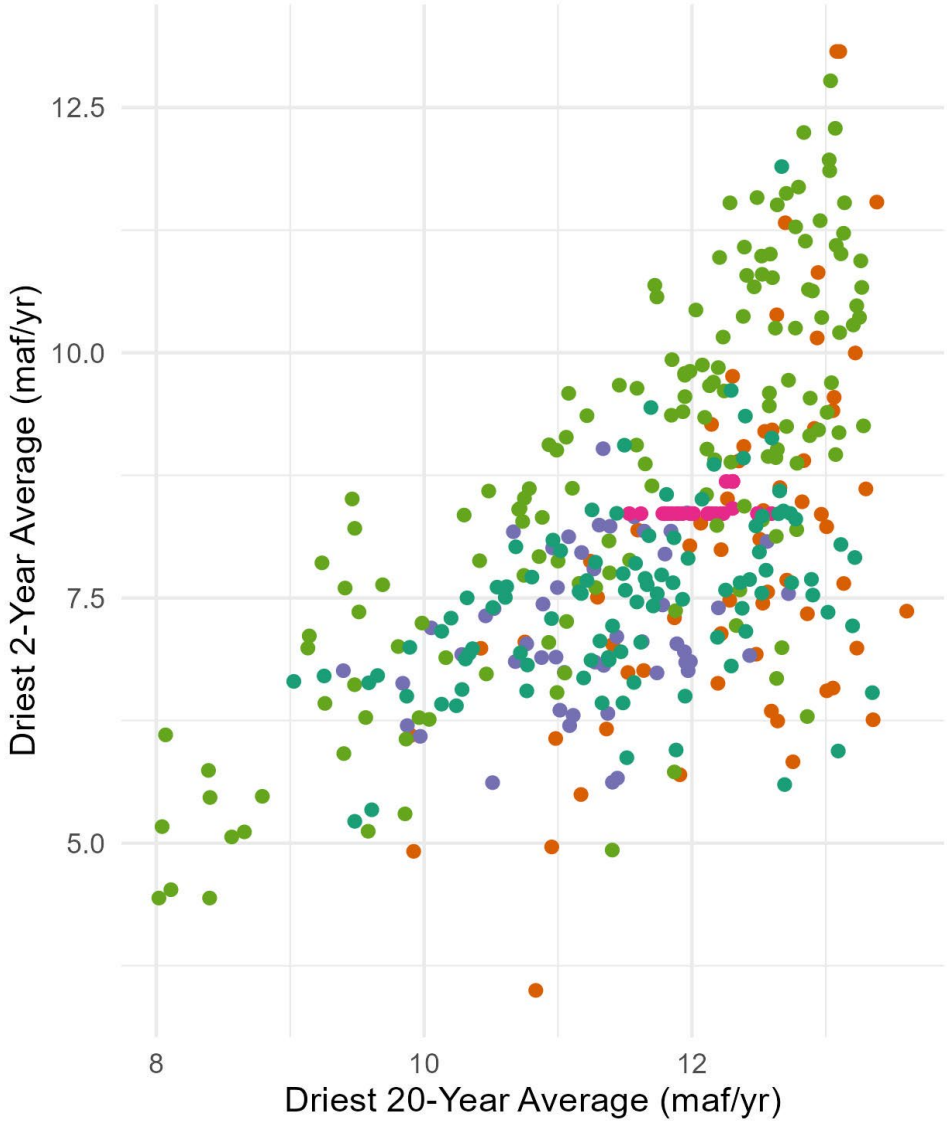

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200 TRACES
strategically selected

- Paleo Drought Resampled (subsampled 50)
- CMIP3 Paleo-Conditioned (subsampled 150)

400 TRACES

The resulting 400-trace ensemble provides broad coverage of plausible hydrologic conditions with minimal gaps.

See Final Environmental Impact Statement (EIS) Appendix F for more information.

A Familiar Model in a Much Broader Analytical Space

Familiar Role

CRSS & RiverWare

Detailed simulation of long-term Colorado River mainstem operations

Final EIS Modeling Approach

8 Operating Alternatives **x** **400** Hydrologic Traces

3,200 CRSS Simulations → Selected CRSS output → **13-15** Resource Models

Thousands of simulated system and resource-specific outcomes spanning a broad range of plausible future conditions

What Can We Learn?

- When are alternatives robust or vulnerable?
- What conditions drive those outcomes?
- What tradeoffs emerge under challenging hydrology?

Shifting the Analytical Focus

Under deep uncertainty, the analysis shifts from summarizing outcomes in terms of probability, risk, frequency, and distribution to understanding the conditions that drive system performance.

Conditional Performance*	How does performance of the alternatives differ under specific hydrologic conditions?
Robustness	Which alternatives meet performance goals across a broad range of hydrologic conditions?
Vulnerability	Under what hydrologic conditions does each alternative fail to meet performance goals?
Conditional Tradeoffs*	How are tradeoffs among competing objectives impacted by hydrologic conditions?

Decision Making under Deep Uncertainty (DMDU) provides an analytical framework for answering these questions.

* Unique analytical approach developed for the Post-2026 Final EIS

Examples from the Post-2026 FEIS

- Conditional performance, robustness, and vulnerability analyses of Lake Powell elevation (Technical Appendix 3.2.1)
- Conditional tradeoff analysis of water delivery and hydrologic metrics (Chapter 2.6.1)
- For detailed figure explanations, see Chapter 3.2.6.

Conditional Performance

- Each year of CRSS output is grouped by hydrologic conditions (here, preceding 3-year average natural flow)

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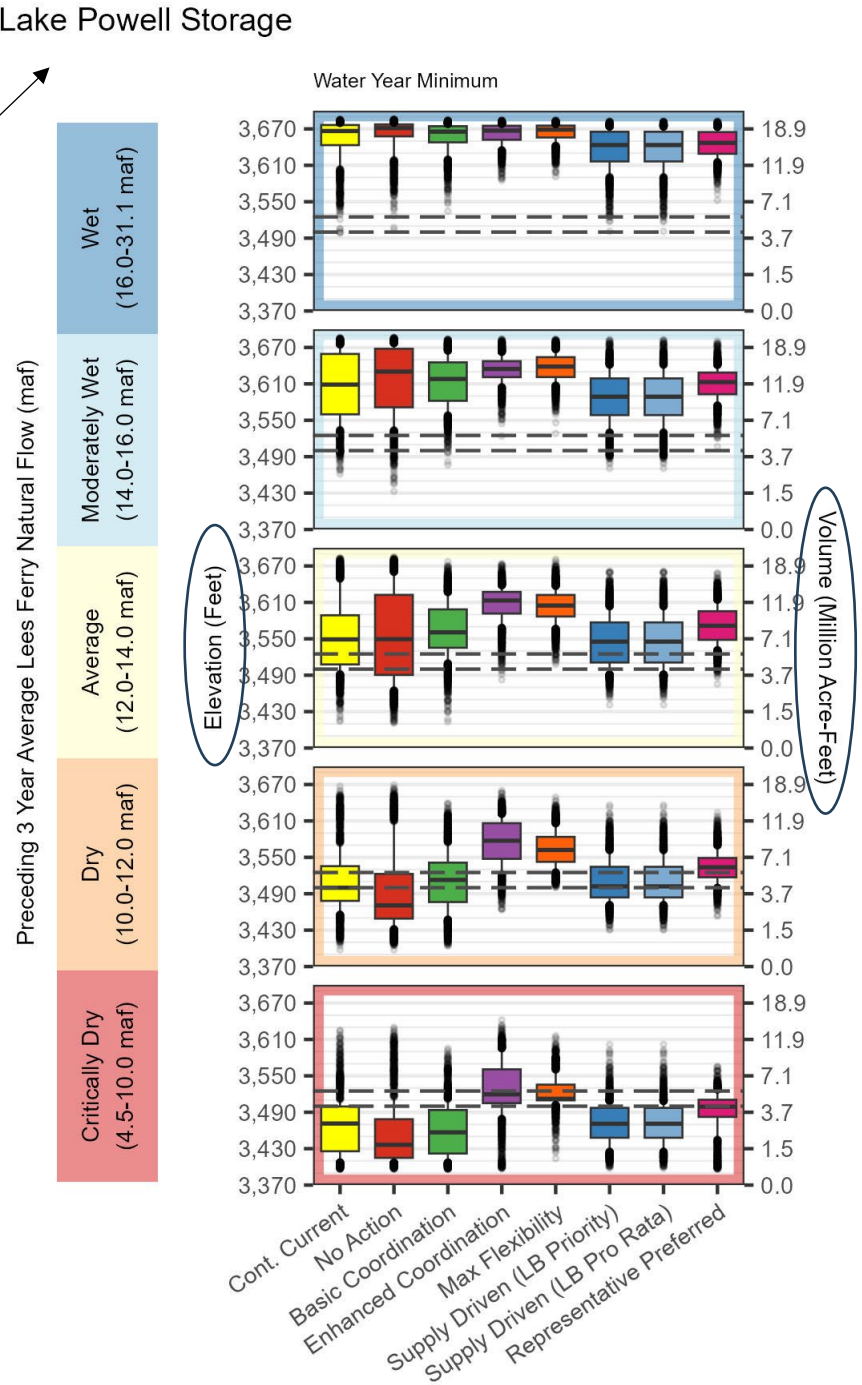
- Outcome of interest (Lake Powell storage) plotted for each hydrologic condition with boxplots. Left axis is elevation, right axis is volume.



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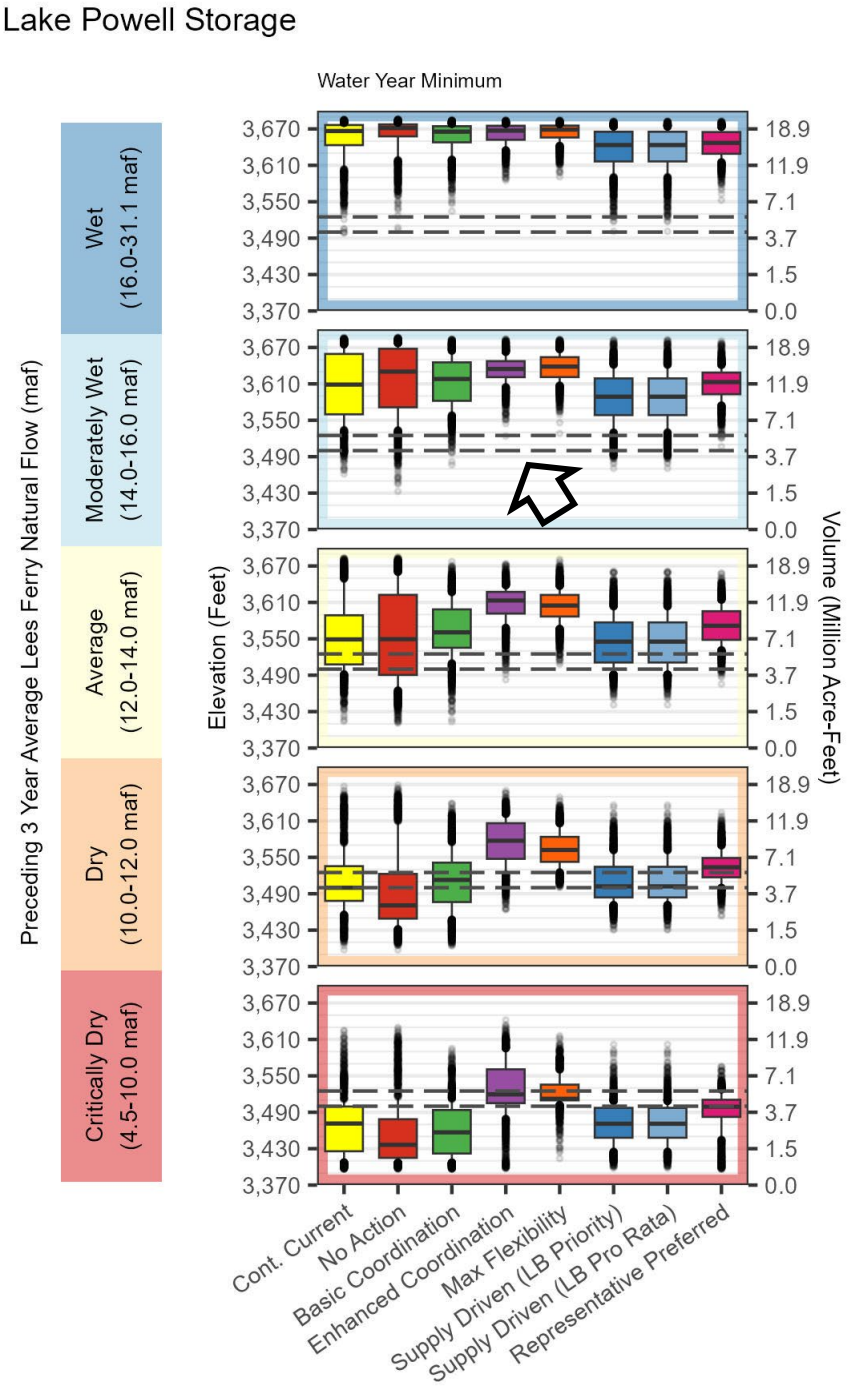
- Dashed lines show important elevations (3,525 and 3,500 feet).



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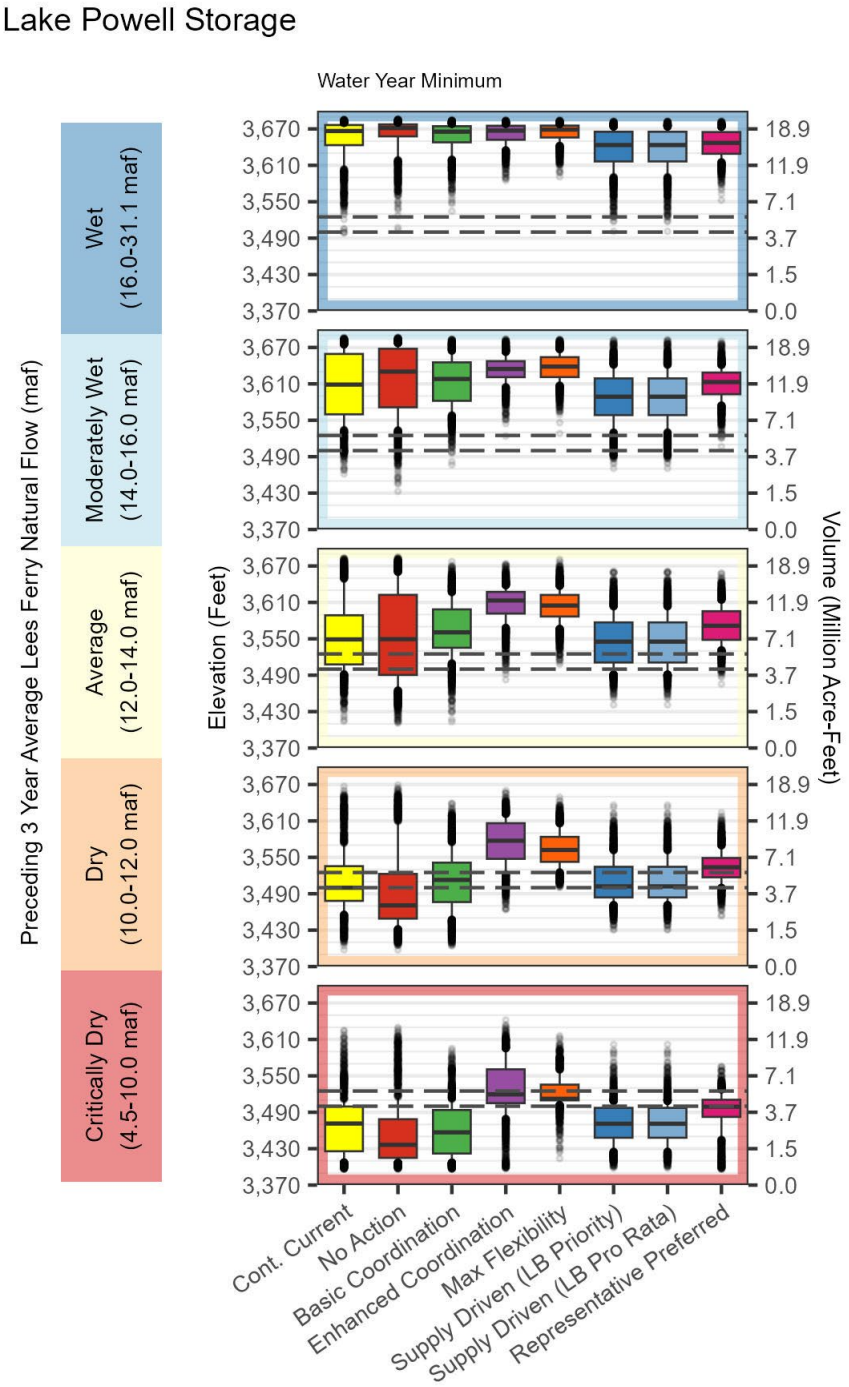
How does performance of the alternatives differ under specific hydrologic conditions?

- In the Average category, 25th percentile elevation is above 3,500 feet for all but No Action alternative.



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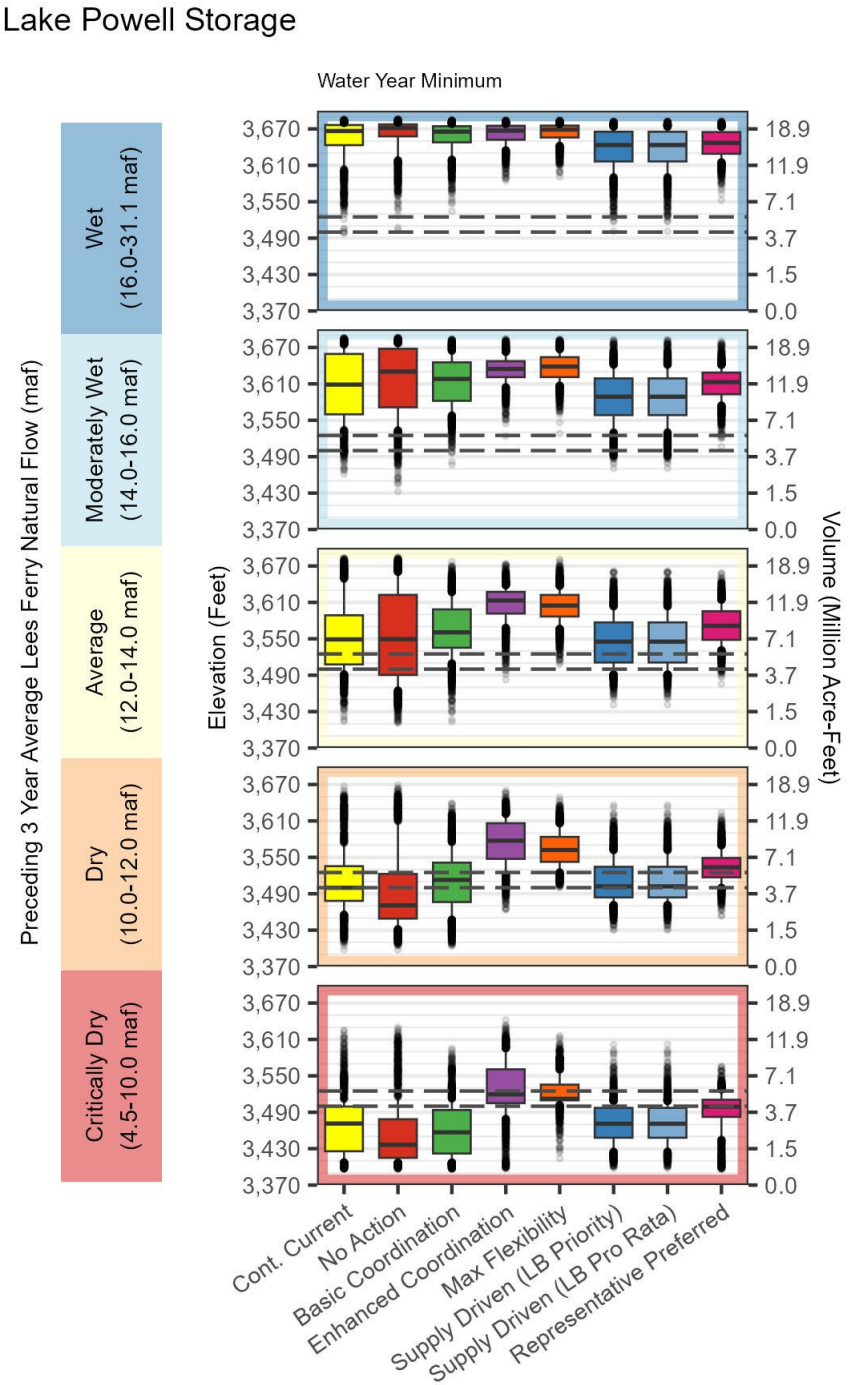
How does performance of the alternatives differ under specific hydrologic conditions?

- In the Average category, 25th percentile elevation is above 3,500 feet for all but No Action alternative.
- In Critically Dry category, only the Enhanced Coordination and Max Flexibility alternatives are above 3,500 feet at the 25th percentile.

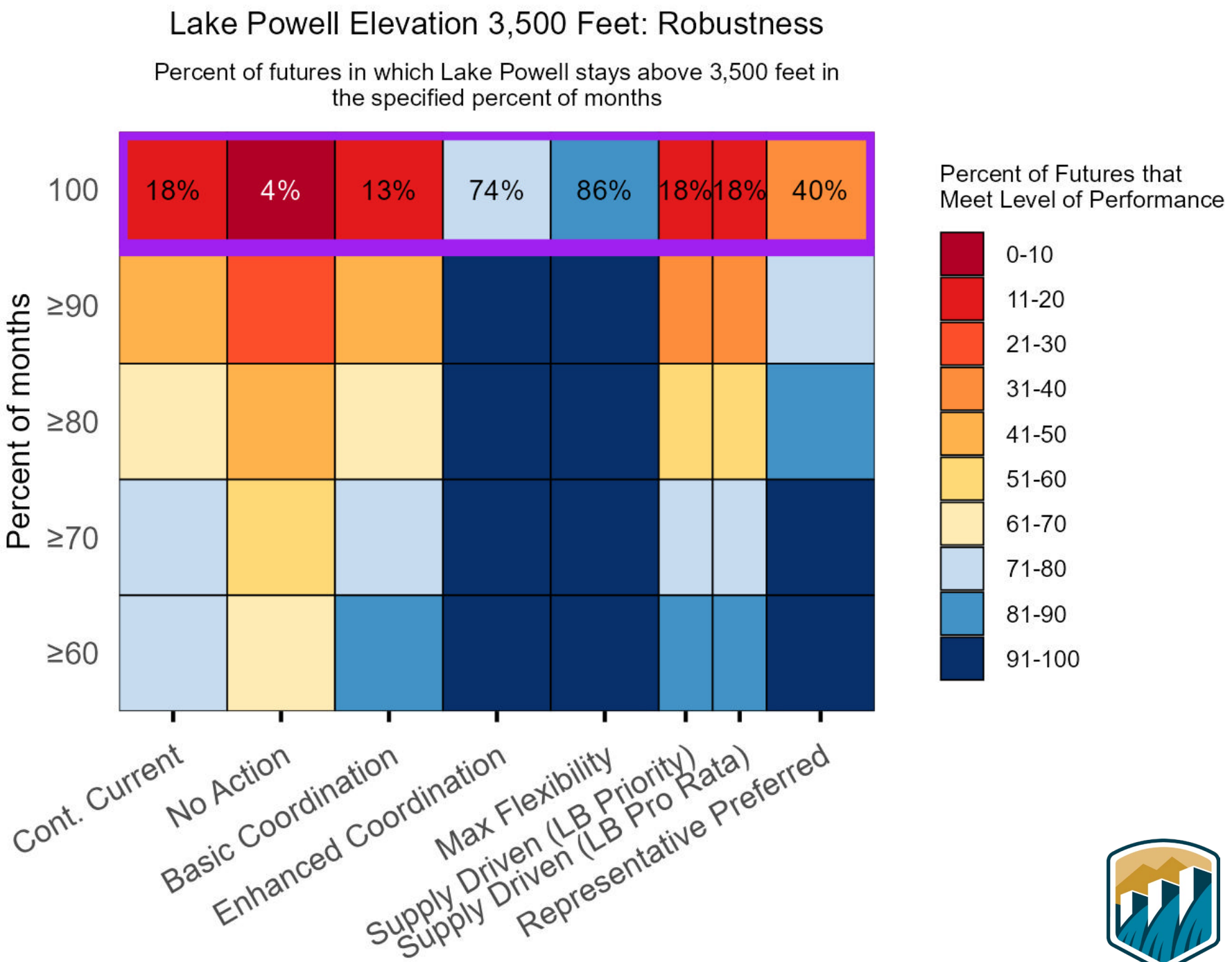


Robustness

- Percent of futures (hydrologic traces) that meet the specified level of performance.
- Level of performance: Lake Powell stays above 3,500 feet in the specified percent of months (rows).
- Top row: hardest to achieve (lowest values)
- Bottom row: easiest to achieve (highest values)
- Purple row is the preferred minimum performance level

Which alternatives meet performance goals in a broad range of conditions?

- Max Flexibility and Enhanced Coordination maintain elevations above 3,500 feet in the highest percentage of hydrologic futures.

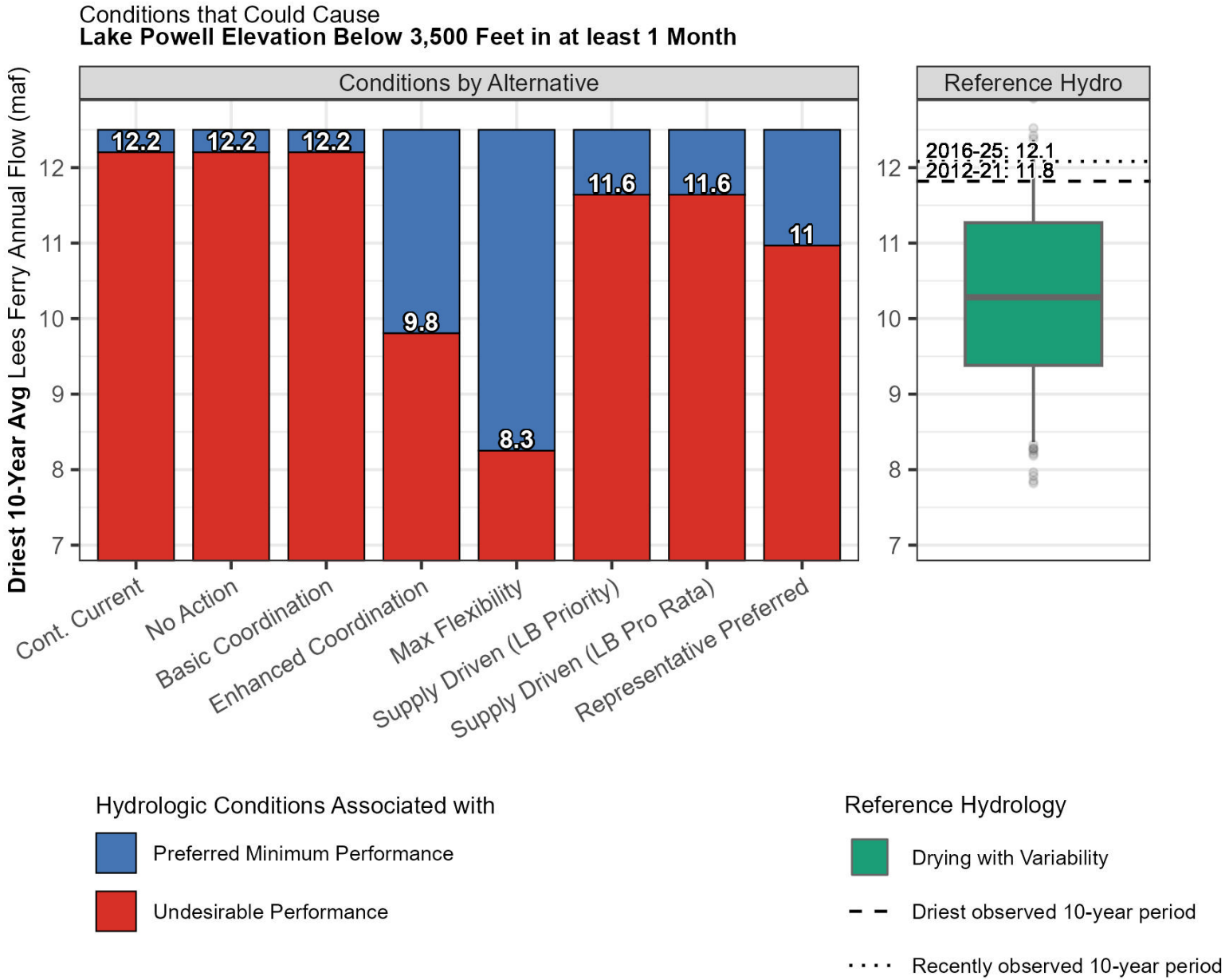


Vulnerability

- y-axis shows the range of driest 10-year periods across all modeled futures
- Blue region: expect elevations always above 3,500 feet
- Red region: expect at least one month below 3,500 feet
- Reference hydrology: lines show recent and driest historical values. Boxplot shows plausible conditions in a drier future

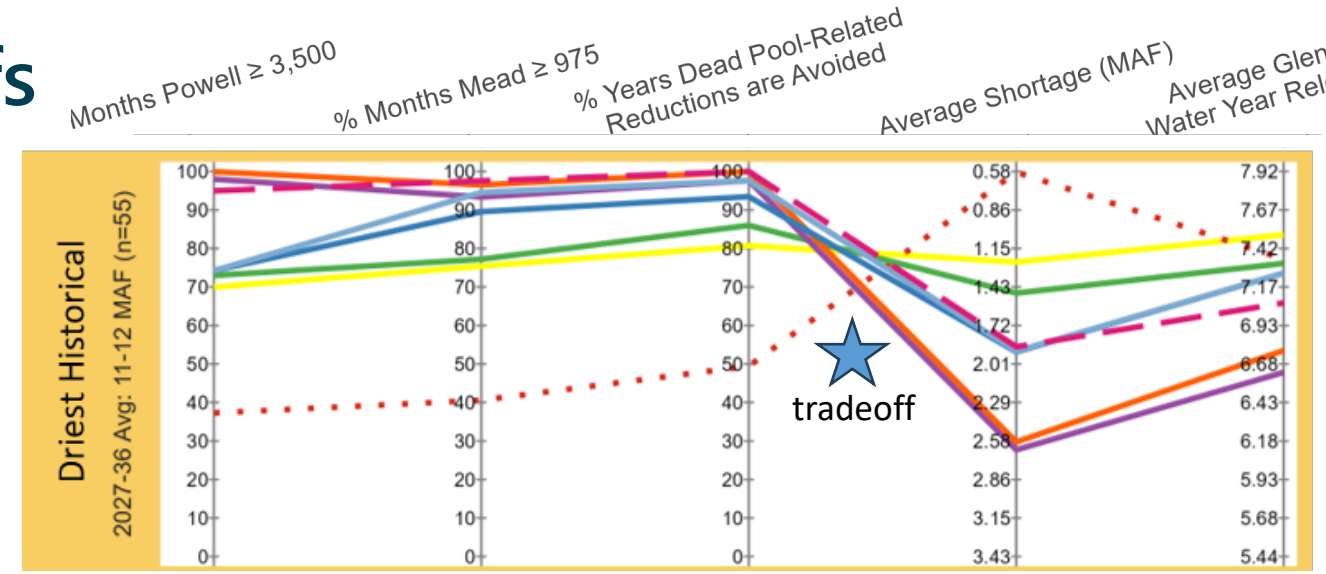
Under what conditions does each alternative fail to meet performance goals?

- Max Flexibility is the least vulnerable, being vulnerable under hydrology significantly drier than historical and reasonably unlikely to occur in a drier future.
- Representative Preferred is not vulnerable to historical conditions, but is reasonably likely to be vulnerable in a drier future.



Conditional Tradeoffs

- Each vertical axis is a performance metric
- Up is better
- Colored lines are alternatives
- Crossing lines indicate a tradeoff



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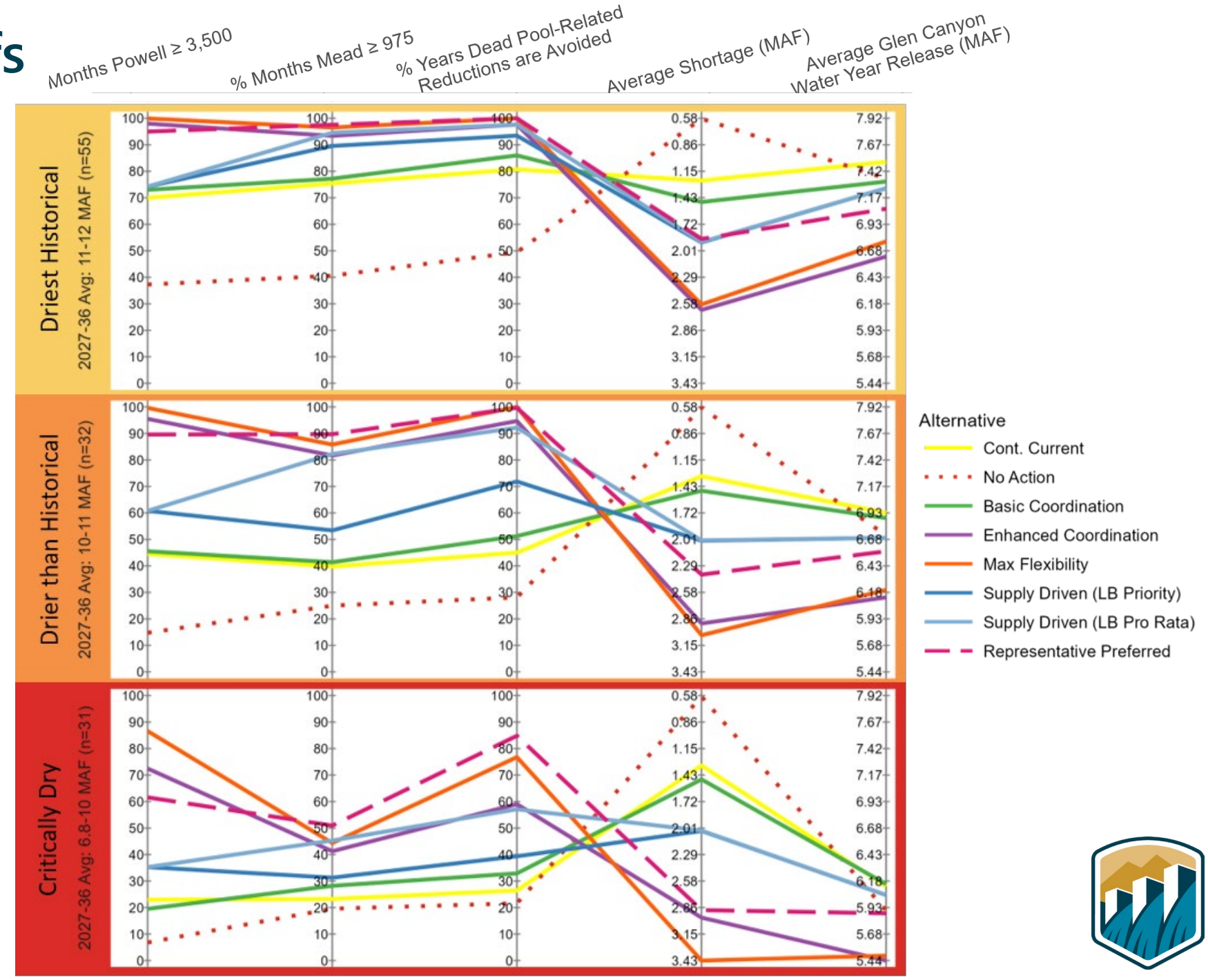
- Tradeoffs shown under increasingly dry hydrologic futures



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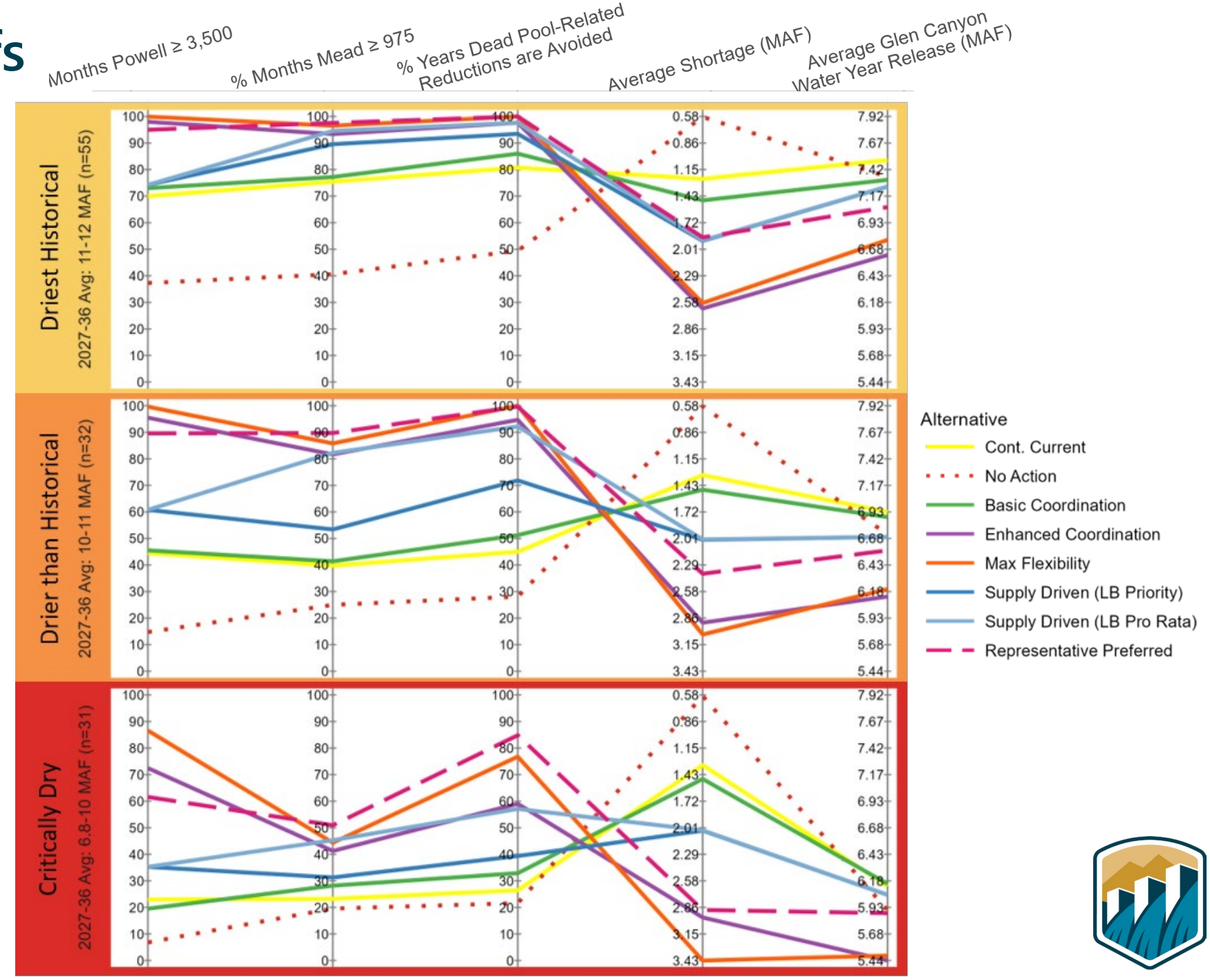

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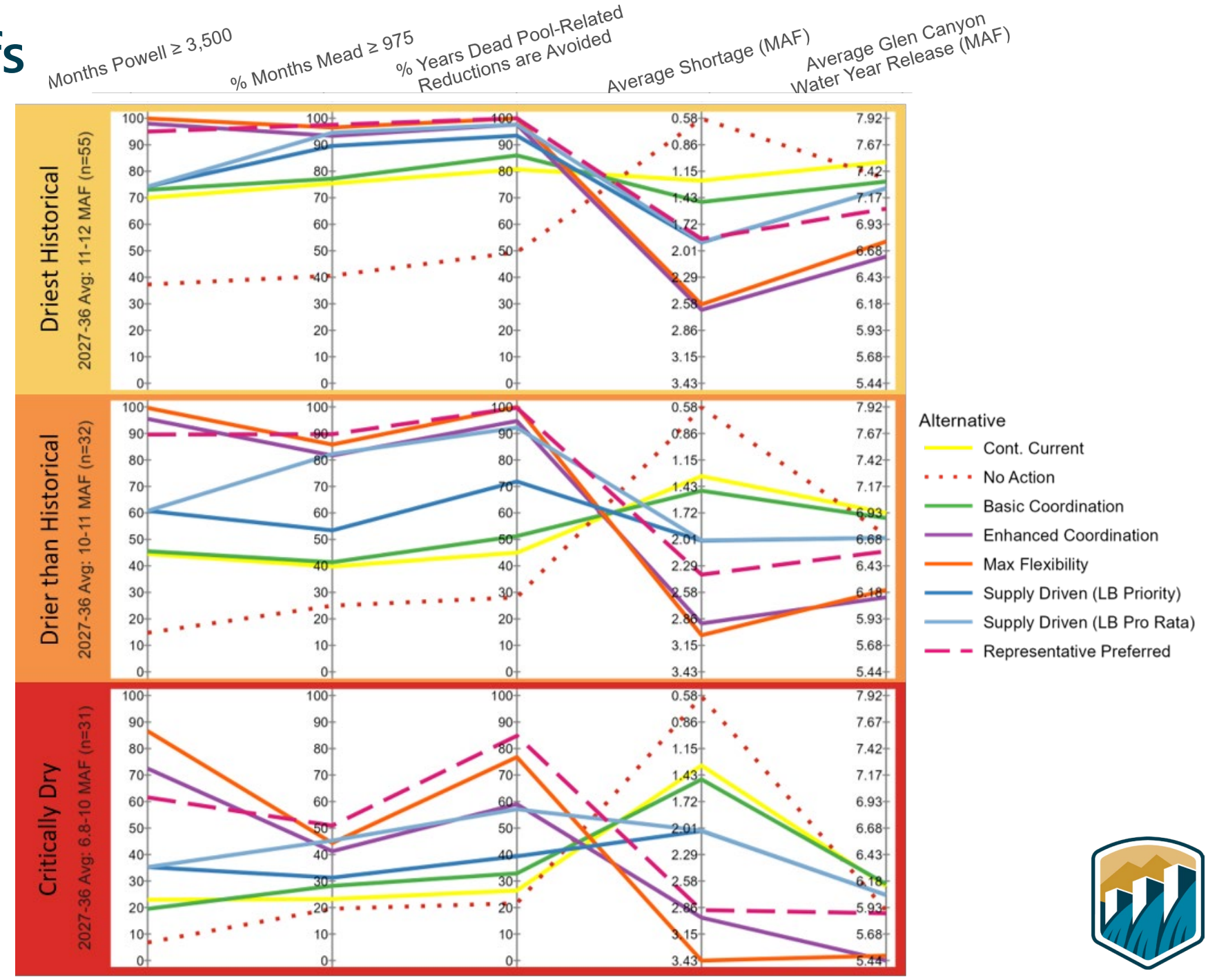
How are tradeoffs impacted by hydrologic conditions?

- In Driest Historical hydrology, all alternatives except No Action perform reasonably well at maintaining important reservoir levels and avoiding dead pool-related reductions.



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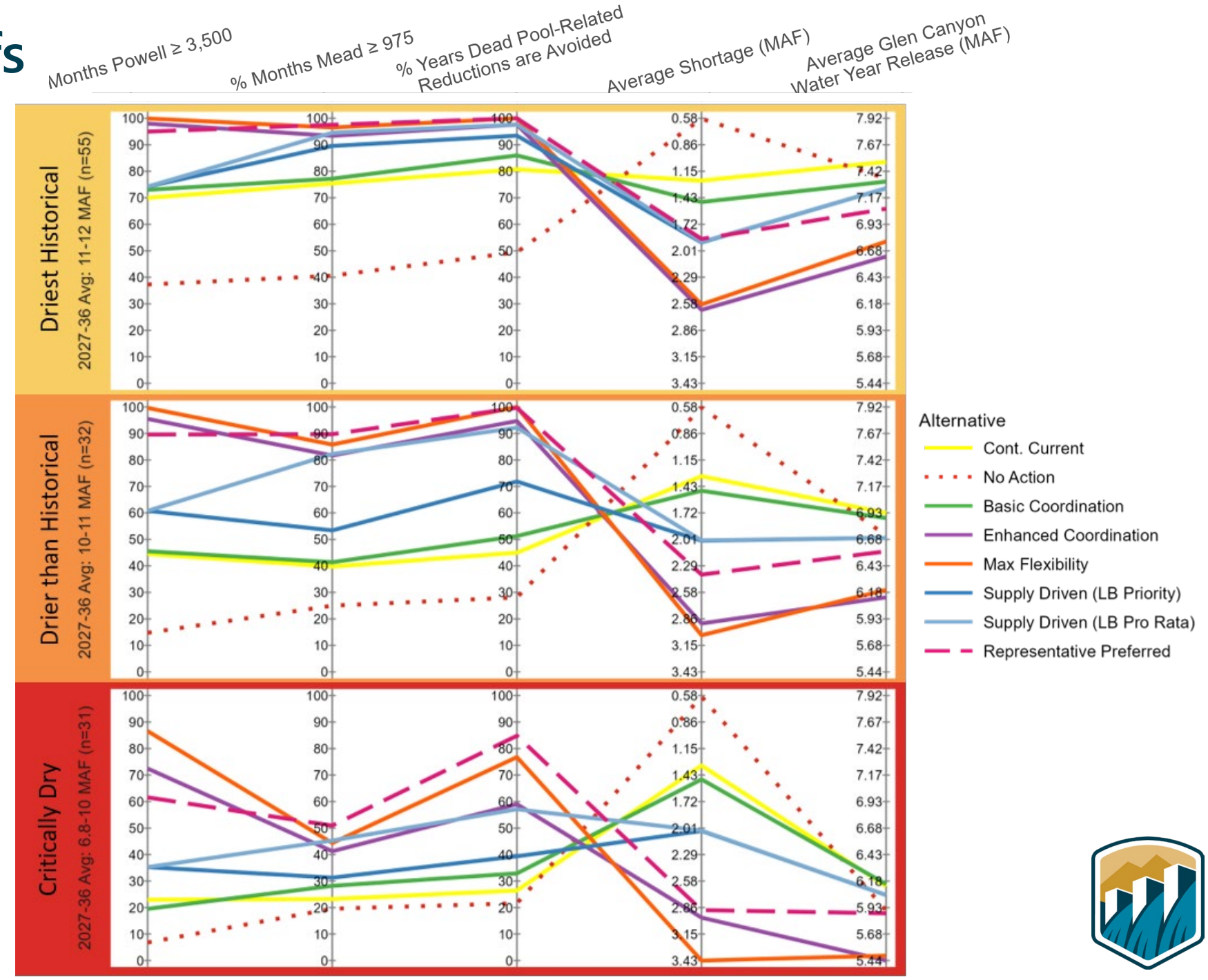
In Critically Dry hydrology, only Enhanced Coordination and Max Flexibility maintain elevations above 3,500 feet more than 70% of the time, but rely on the smallest average releases from Glen Canyon.



What Does DMDU Add to Post-2026 Final EIS?

- Provides a decision-relevant understanding of Colorado River system behavior across a wide range of plausible futures
- Shifts the focus from "What will happen?" to "What hydrologic conditions cause the system to become vulnerable?"
- Identifies the hydrologic and system conditions associated with vulnerabilities, including when and where tradeoffs among system metrics are present
- Turns a large ensemble of simulated futures into information about system behavior, vulnerabilities, and tradeoffs, supporting a robust comparison of Post-2026 Final EIS alternatives
  - Conditional analyses reveal important differences across futures that can be obscured by full-ensemble summary statistics

Future Directions

- Extend DMDU methods to mid-term planning (e.g., 2–5 years) to bring vulnerability-based analysis into operational projections
  - Ongoing research with Kasprzyk, Zagona, and Carpenter is exploring this application
- Improve RiverWare/RiverSMART output data management to support large and complex data analyses
  - Working with CADSWES to evaluate more scalable approaches, including Parquet-based storage with query-able directory structures

Questions

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Post-2026 Operational Guidelines and Strategies for Lake Powell and Lake Mead – Final Environmental Impact Statement: https://www.usbr.gov/ColoradoRiverBasin/post2026/final-eis/index.html