BUREAU OF RECLAMATION

Downscaling Approaches & Hydrologies developed for the Colorado River Simulation System

Water Utility Climate Alliance
July 20, 2022

James Prairie, PhD, Modeling and Research Group Chief, Upper Colorado Basin Region

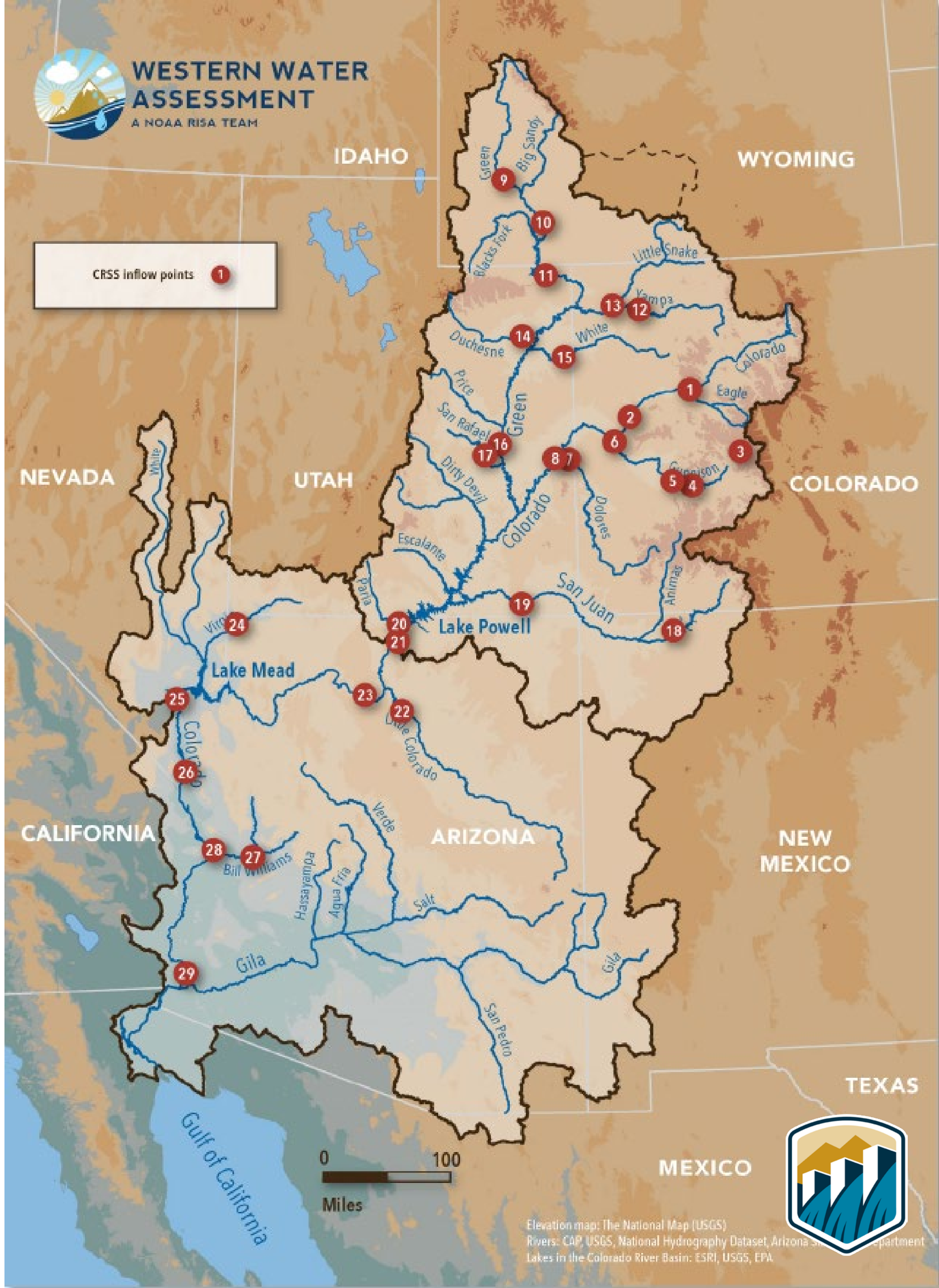
Overview

- Past approaches
- Approaches under development
- Full set of available hydrologies
- Challenges working with many hydrologies
    - Decision Science app development

Past Approaches

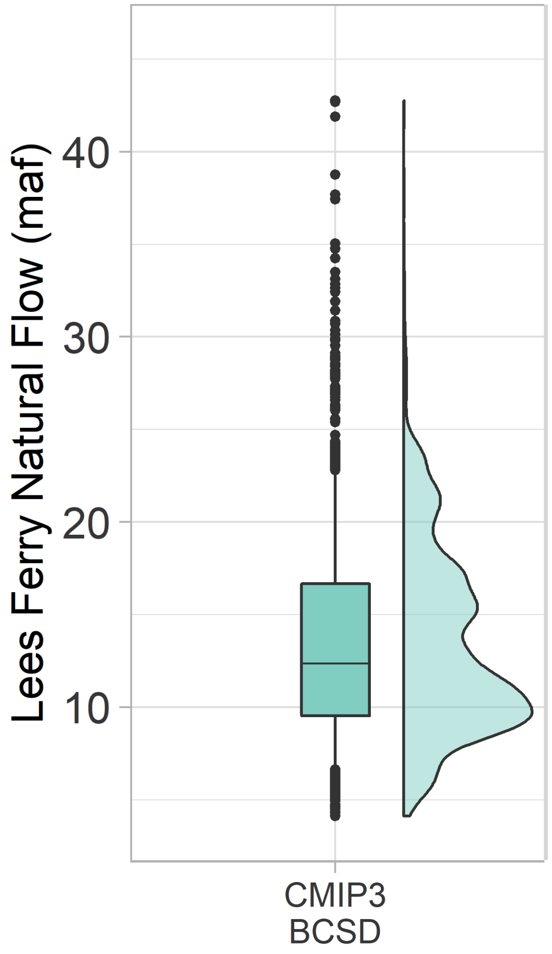
- CMIP3 BCSD
  - All 29 sites for CRSS
  - First used in the 2012 Colorado River Basin Study

- CMIP3 WRF
  - Only Lees Ferry for CRSS
- CMIP5 WRF
  - Only Lees Ferry for CRSS



Distrubution of CMIP Hydrology Scenarios for Modeling Time Horizon (2022-2060)

Colorado River Natural Flow at Lees Ferry Gaging Station, Arizona



Several datasets of downscaled climate projections are available and have been used in analyses for the CRB

Only a subset are available for use in the Colorado River Simulation System (CRSS)

Colorado River Basin Climate and Hydrology State of the Science, April 2020

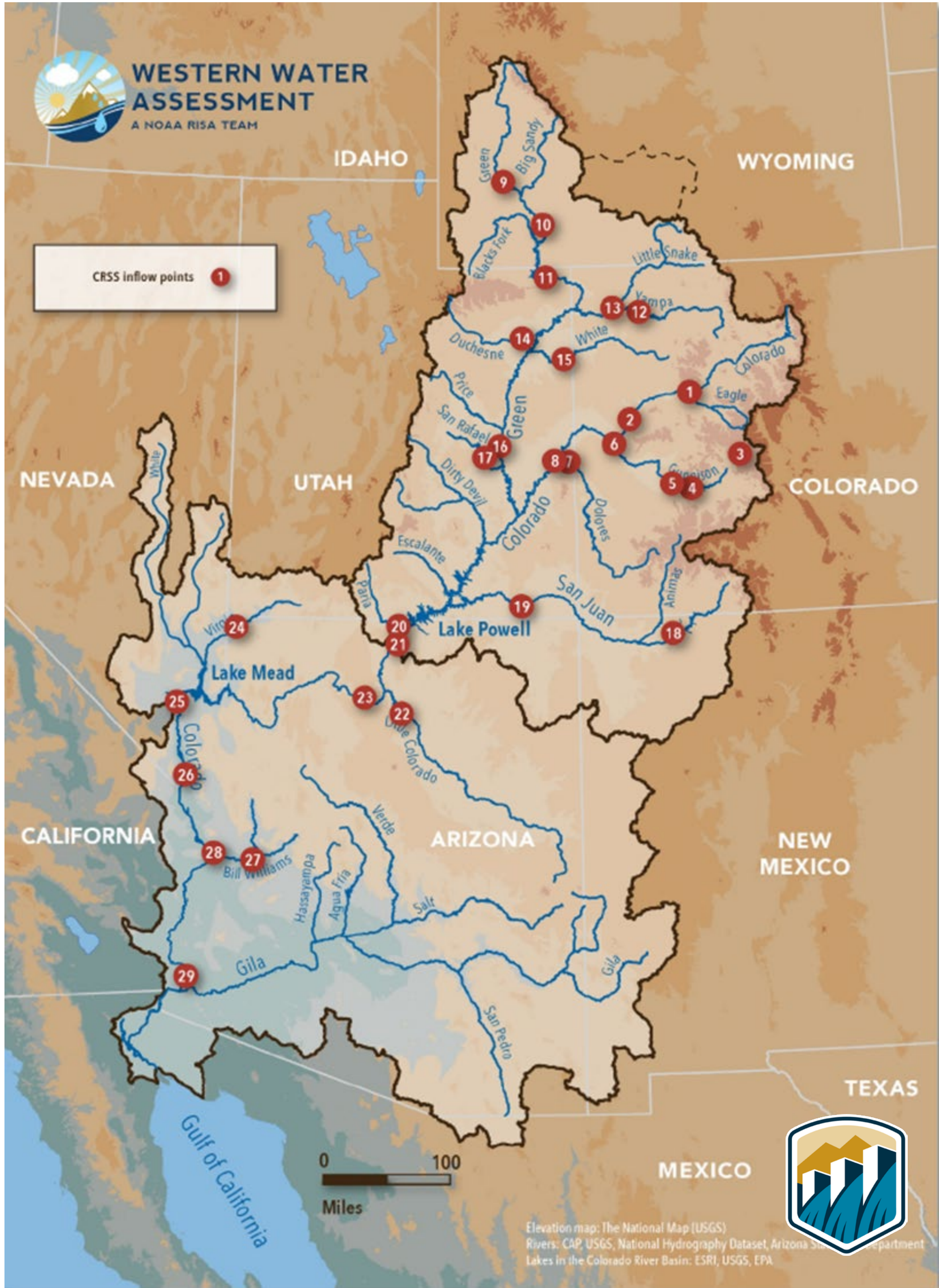
Table 11.3

Selected widely used and publicly available datasets of downscaled climate projections covering the conterminous U.S. or larger domains that are based on the downscaling methods discussed in this chapter. See the text for references to technical literature describing these methods and datasets. Note that there may be other available datasets produced using the same methods or variants of them. Time step M=monthly, D=daily

Dataset name	Downscaling Method	GCM data	Observed climate data for bias-correction	# Runs	Spatial Resolution	Time step	Associated hydrology-model output available?	Visualization tool that shows these data?
Statistically downscaled datasets								
Reclamation et al. CMIP5 BCSD	Bias-Corrected Spatial Disaggregation	CMIP5; 37 GCMs	Maurer et al. (2002)	231	12 km	M	Yes	No
NASA NEX-DCP30 (in USGS Nat'l Climate Change Viewer)	Bias-Corrected Spatial Disaggrega--tion (variant)	CMIP5; 33 GCMs	PRISM	>100	0.8 km	M	Yes	Yes – USGS National Climate Change Viewer
Reclamation et al. CMIP5 LOCA	Locally Constructed Analogs	CMIP5; 32 GCMs	Livneh et al. (2015)	64	6 km	D	Yes	Yes – NOAA Climate Explorer v2
Reclamation et al. CMIP5 BCCA	Bias-Correction Constructed Analogs	CMIP5; 32 GCMs	Maurer et al. (2002)	134	12 km	D	Yes	No
MACAv2, U. of Idaho (2 variants)	Multivariate Adaptive Constructed Analogs	CMIP5; 20 GCMs	METDATA; Abotzoglou (2013), or Livneh et al. (2013)	40	4 km, or 6 km	D	No	Yes; Climate Toolbox Climate Mapper
Dynamically downscaled datasets								
NARCCAP	Dynamical; 6 RCMs	CMIP3; 4 GCMs	Maurer et al. (2002)	12	50 km	D	No	No
NA-CORDEX	Dynamical; 6 RCMs	CMIP5; 6 GCMs	METDATA; Abatzoglou (2013)	35	25 km or 50 km	D	No	No

Approaches Under Development

- CMIP5 BCSD
  - All 29 sites for CRSS
- CMIP5 LOCA
  - All 29 sites for the CRSS
- CMIP5 EnGARD
  - All 29 sites for the CRSS
- CMIP5 ICAR
  - All 29 sites for the CRSS
- CMIP6 ICAR
  - All 29 sites for the CRSS



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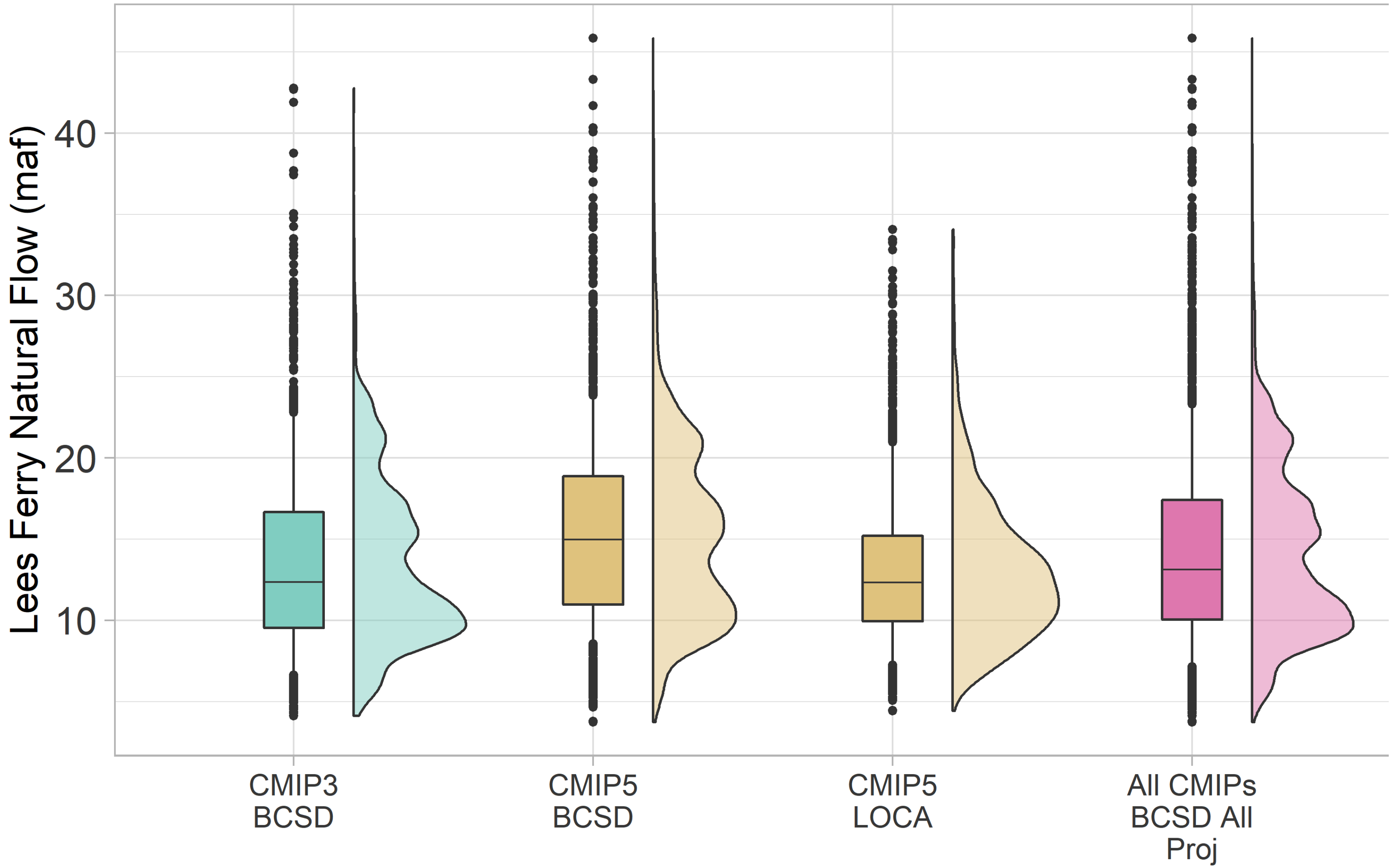

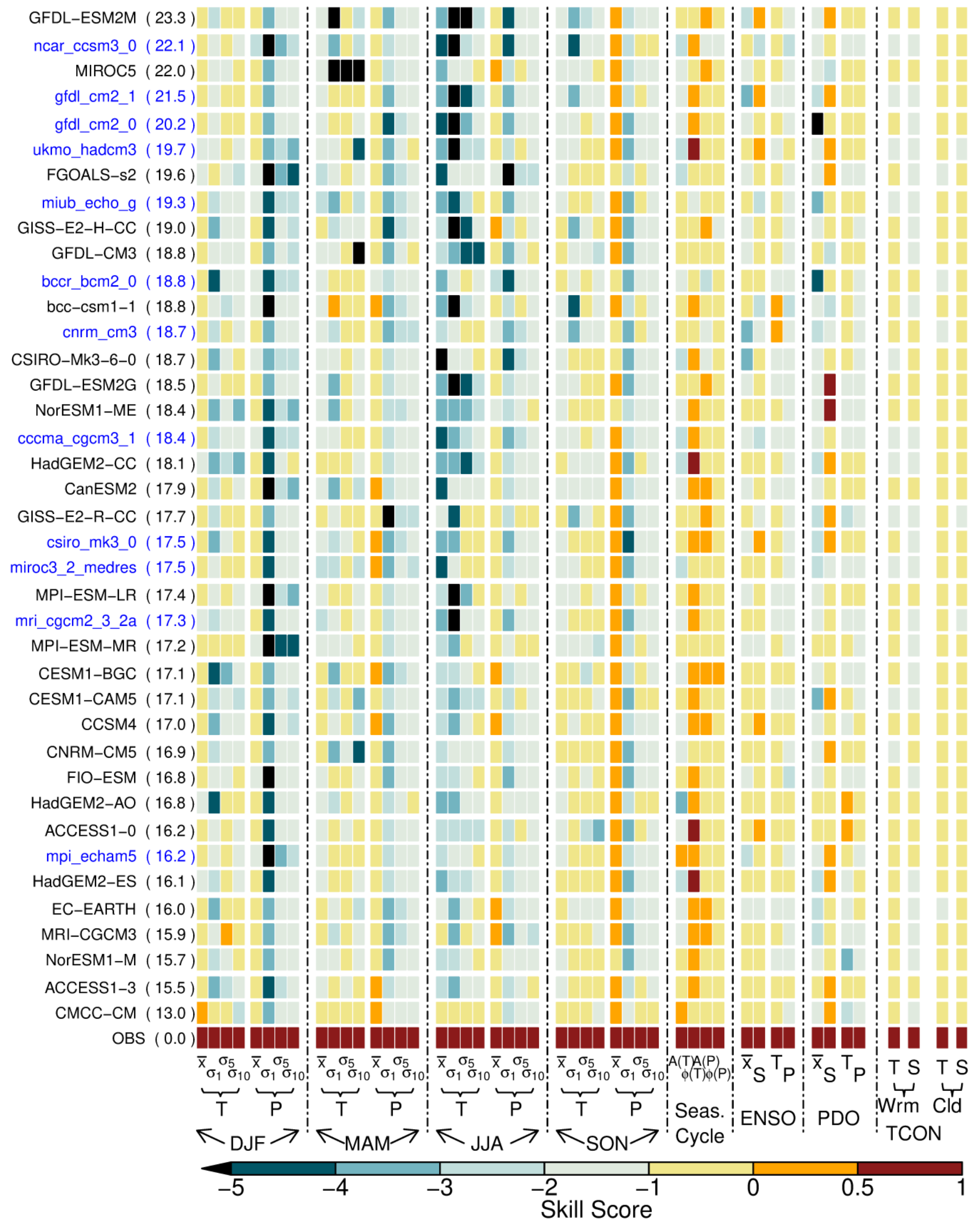

GCM Culling

- Approaches for GCM selection
- Typically based on GCM regional performance
  - Seasonal mean precipitation (P) and temperature (T)
  - Seasonal variability
  - Climate variability
  - Teleconnections

David Pierce, Scripps Institute, 2019

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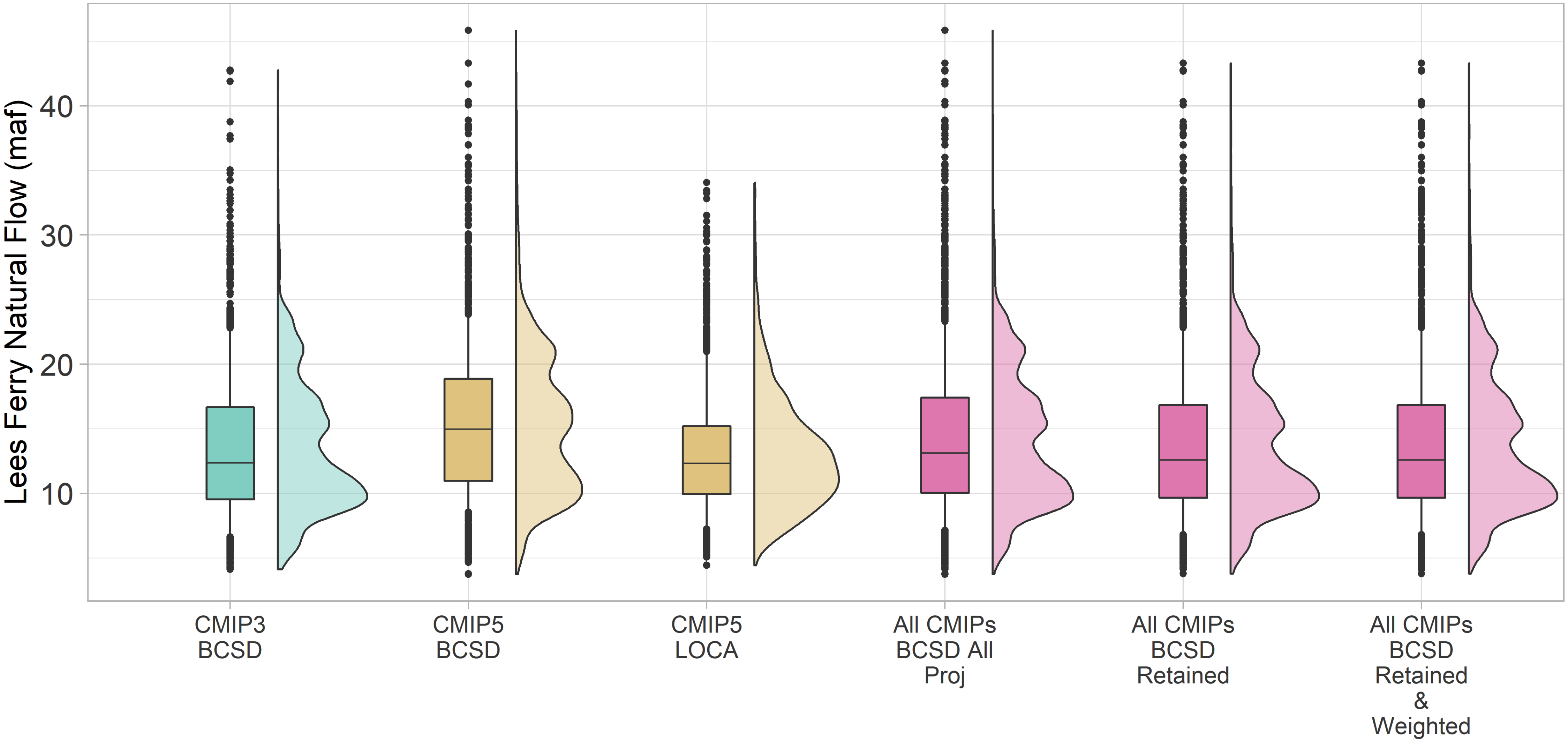

Many methods availabale to incorporate hydrologic uncertainty

<table>
<tr><th>Ensemble Category</th><th colspan="3">Types of Ensembles</th></tr>
<tr><td rowspan="4">Resampled Historical Streamflow</td><td colspan="3">Full observed Record (1906-2019)</td></tr>
<tr><td colspan="3">Subset of Observed Record:</td></tr>
<tr><td>1988-2019
(Stress Test)</td><td>1931-2019
(Early Pluvial Removed)</td><td>2000-2019
(New Normal Hydrology)</td></tr>
<tr><td colspan="3">Paleo Record</td></tr>
<tr><td rowspan="2">GCM-based</td><td colspan="3">CMIP3 ensemble</td></tr>
<tr><td colspan="3">CMIP5 ensemble (under development)</td></tr>
<tr><td rowspan="2">Blended</td><td colspan="3">Paleo-conditioned</td></tr>
<tr><td colspan="3">GCM-conditioned (under development)</td></tr>
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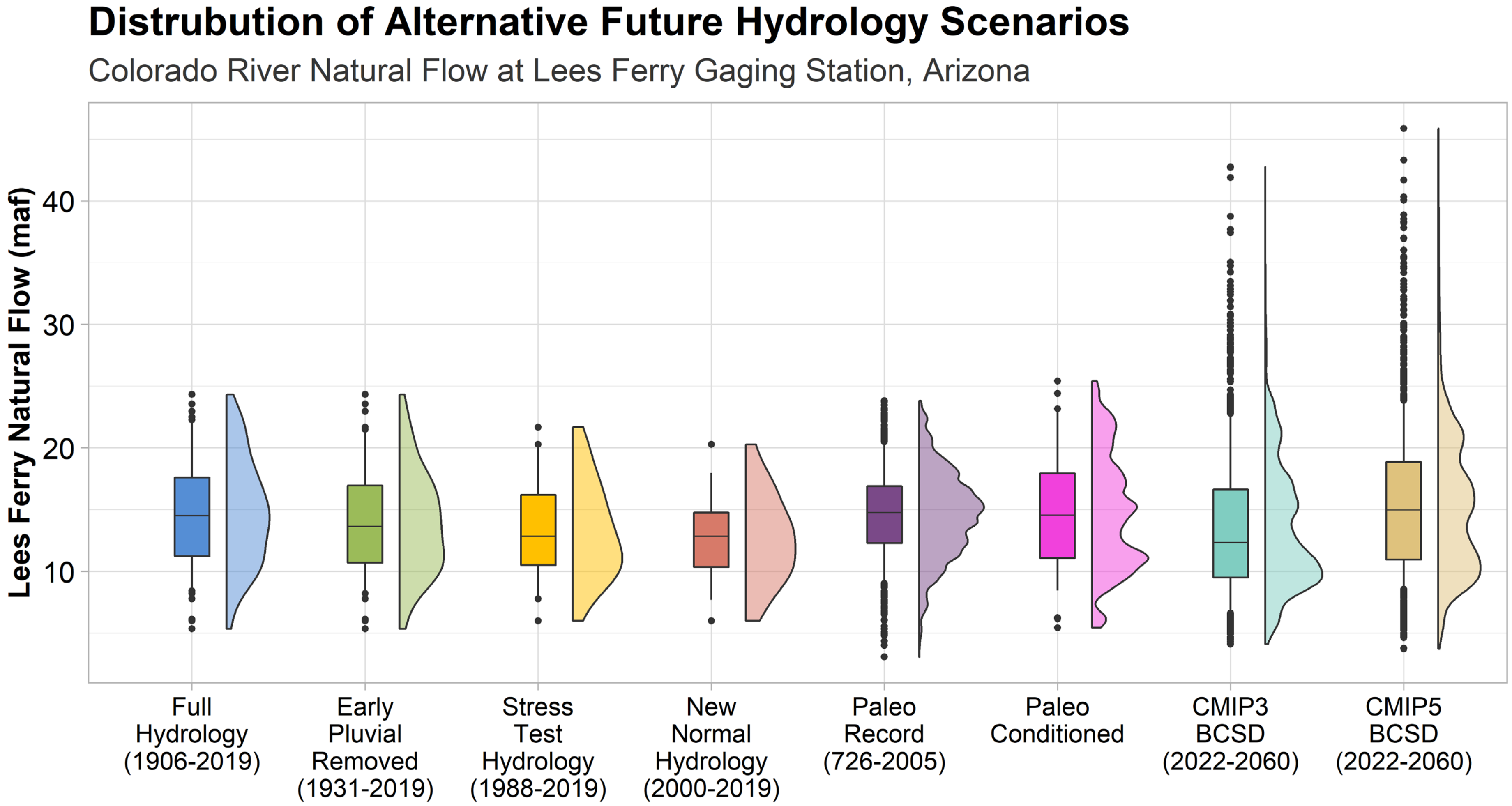
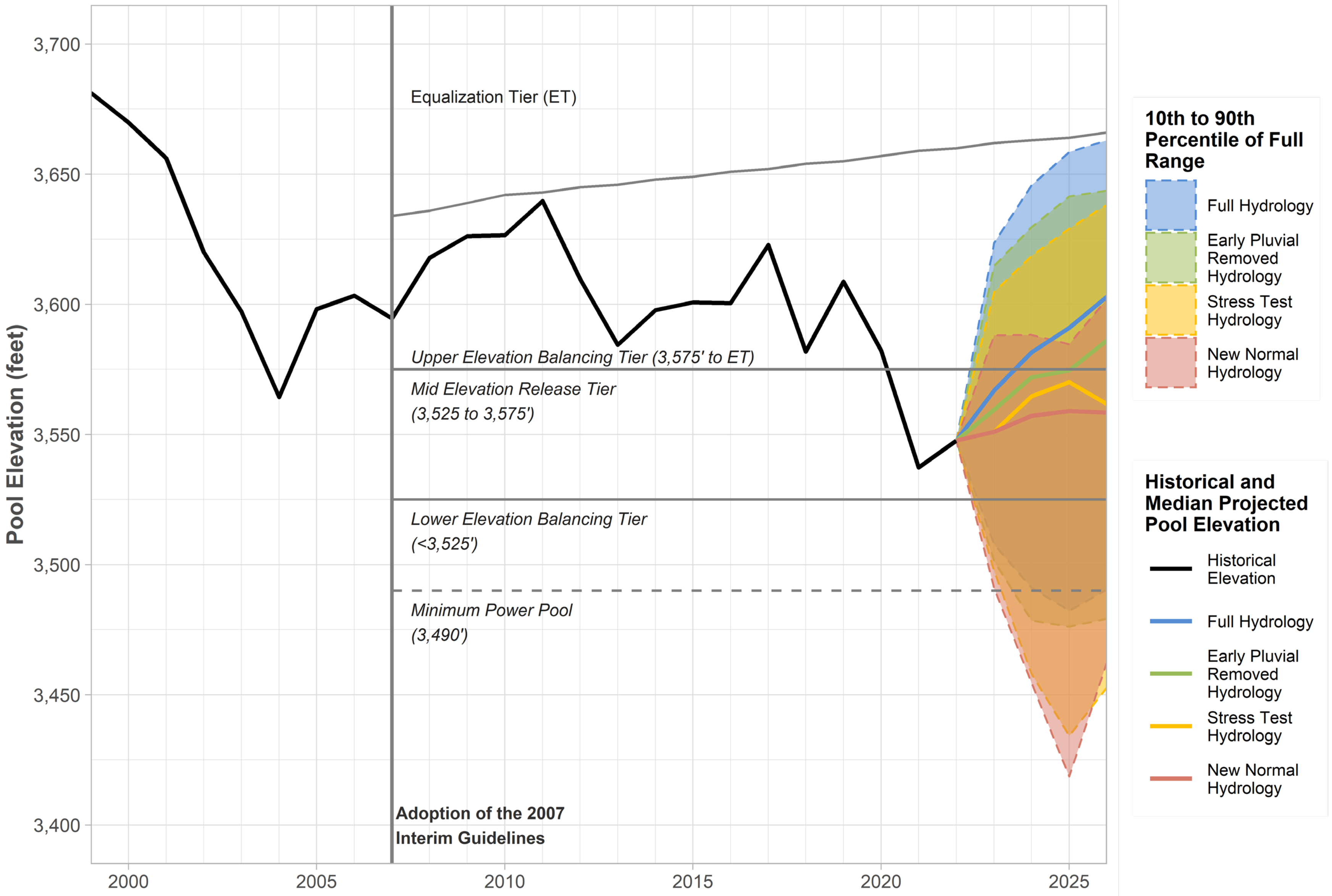
Distributions for multiple Hydrology Scenarios
Colorado River natural Flow at Lees Ferry Gaging Station



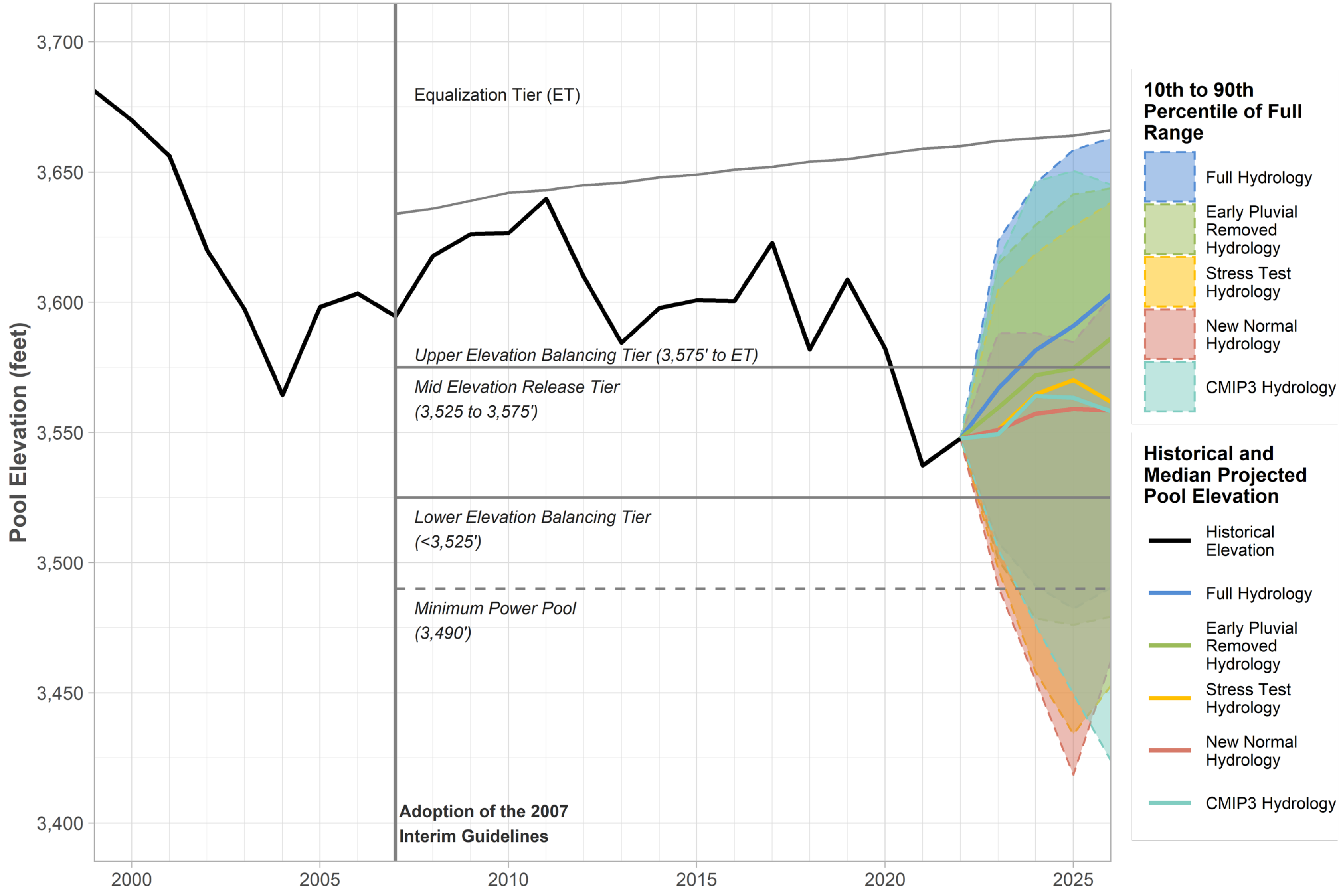
Avg Ann Flow (maf)	14.76	13.92	13.14	12.43	14.65	14.79	13.48	15.22

Historical and Future Projected Lake Powell End-of-December Elevations



All projections are produced using the January 2022 Official CRSS model.
Full Hydrology uses 114 hydrologic inflow sequences based on resampling of the observed natural flow record from 1906-2019.
Early Pluvial Removed Hydrology uses 89 hydrologic inflow sequences based on resampling of the observed natural flow record from 1931-2019.
Stress Test Hydrology uses 32 hydrologic inflow sequences based on resampling of the observed natural flow record from 1988-2019.
New Normal Hydrology uses 20 hydrologic inflow sequences based on resampling of the observed natural flow record from 2000-2019.

Historical and Future Projected Lake Powell End-of-December Elevations



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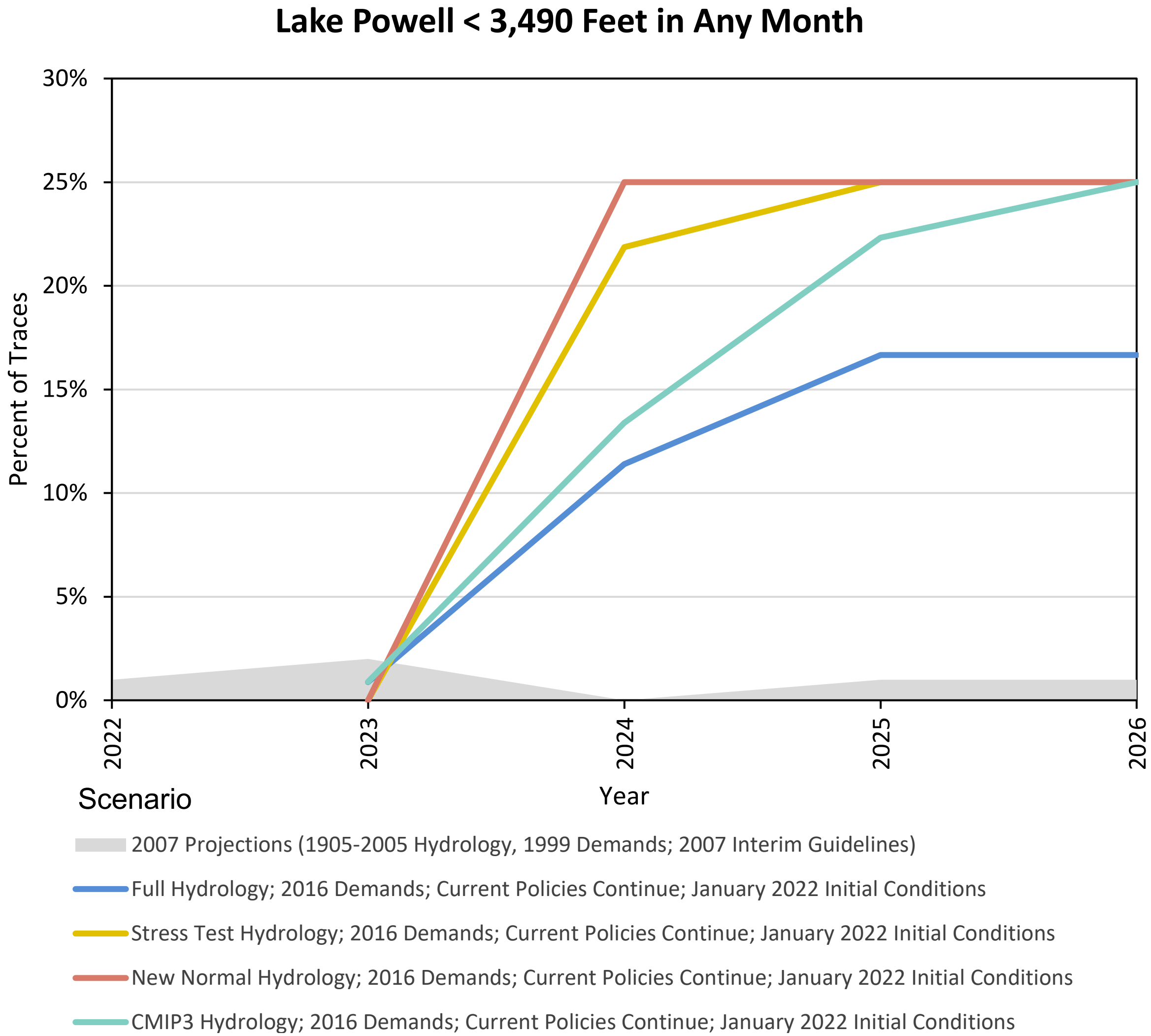
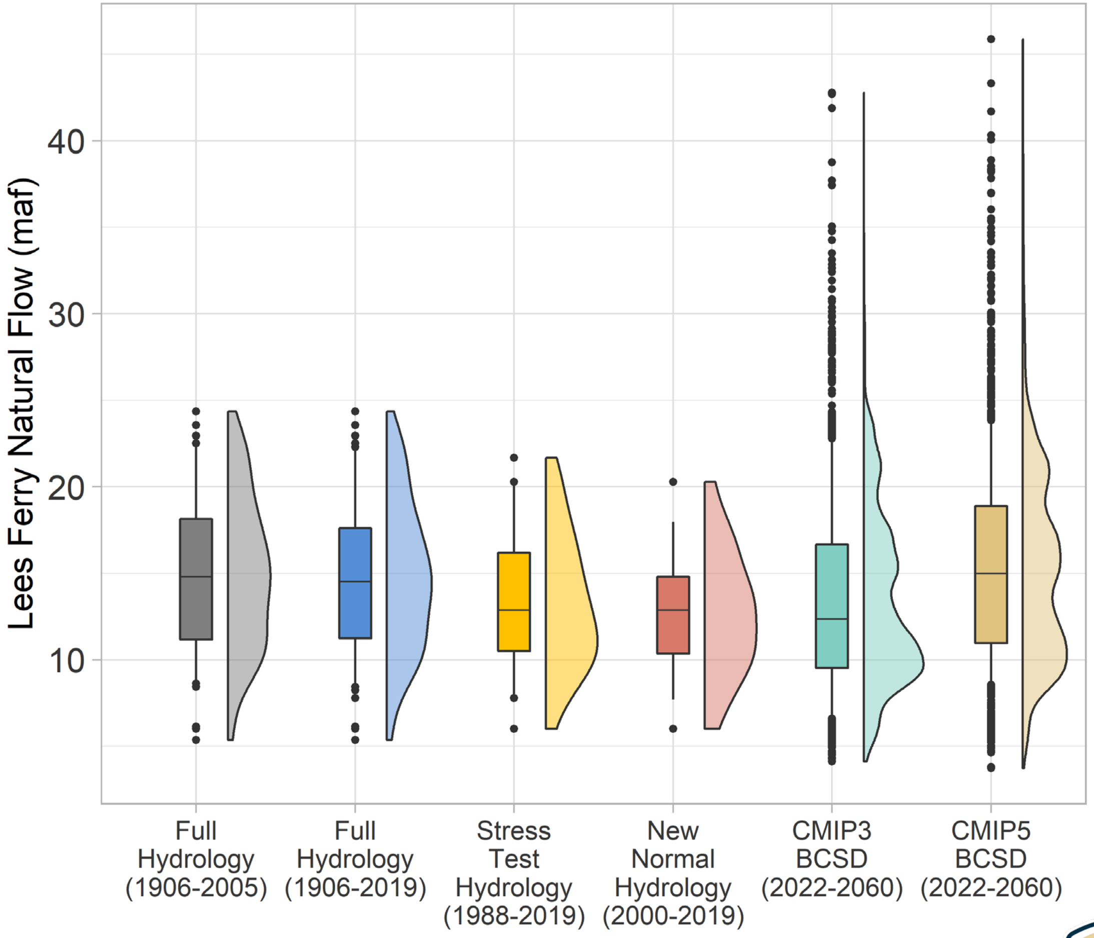
New Normal Hydrology uses 20 hydrologic inflow sequences based on resampling of the observed natural flow record from 2000-2019.
CMIP3 Hydrology uses 112 hydrologic inflow sequences based on downscaled CMIP3 GCM projections.

What is the risk of Lake Powell dropping below 3,490 feet (minimum power pool) in any month?[1,2]



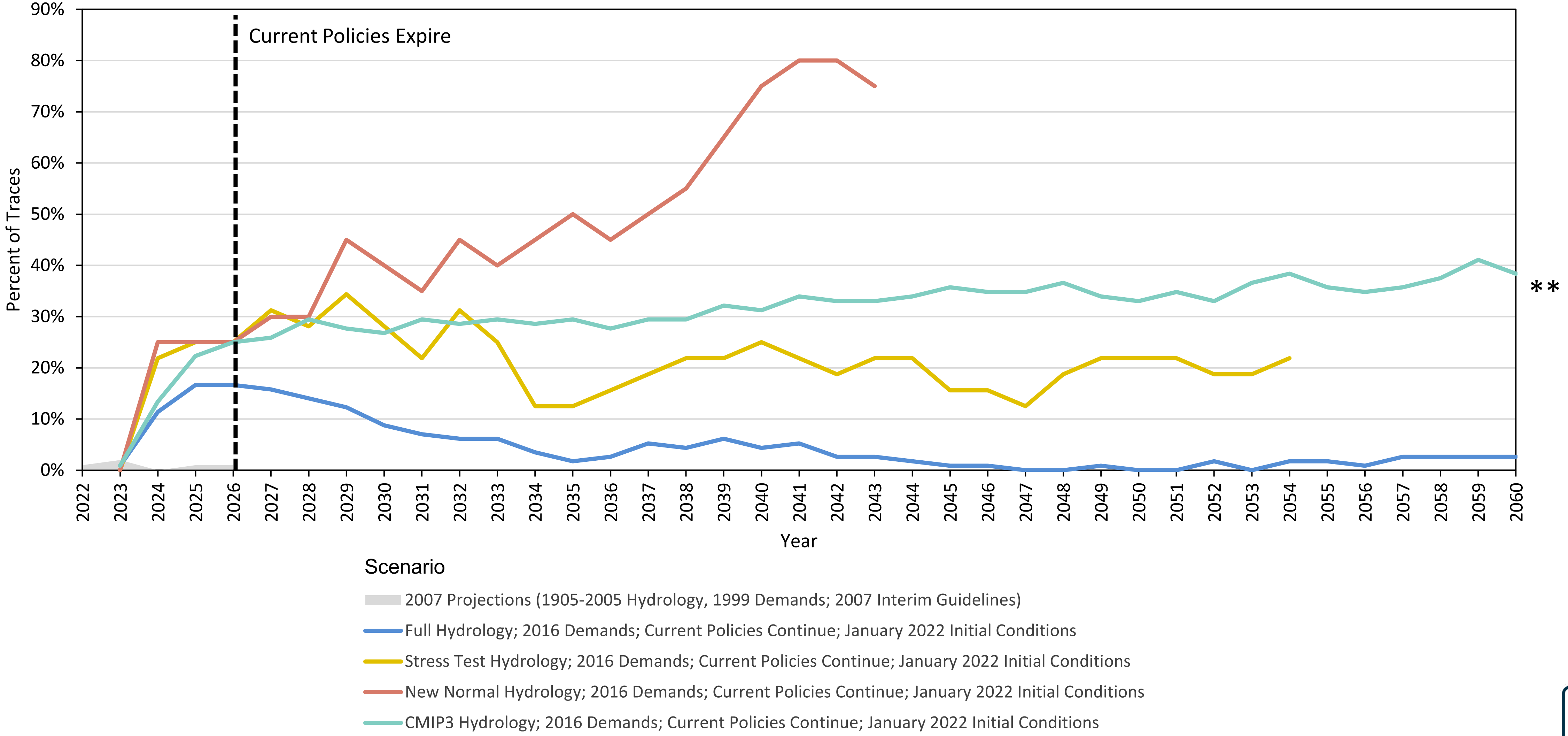


[1]Not official projections; based on January 2022 CRSS modeling with Lake Powell initial elevation of 3,548 feet. [2]Lake Powell's Powell's 7/18/22 elevation is 3,538 feet

** CMIP3 and CMIP5 ensembles span 3 different emissions futures and were downscaled using Bias Correction Spatial Downscaling (BCSD)

Shifting Risk

Risk of Lake Powell dropping below 3,490 feet in any month



* Not Official Projections; based on January 2022 CRSS modeling with Lake Powell initial elevation of 3,548 feet. Lake Powell's 7/18/22 elevation is 3,538 feet

** CMIP3 ensemble spans 3 different emissions futures and were downscaled using Bias Correction Spatial Downscaling (BCSD)

Concerns when Planning under Deep Uncertainty

- **Deep uncertainty** occurs when probabilities of any given set of future conditions cannot be estimated with confidence
  - Translation: it is impossible to determine the most appropriate planning assumptions

- Choices of hydrologic ensemble and other assumptions about the future are likely to be controversial

- Statistics-based analysis may be unreliable as the sole basis for understanding system or planning for future
  - Risk – defined as percent of traces; *completely dependent on the composition of the chosen ensemble of traces*
  - "acceptable" level of risk, risk reduction, etc. are common planning metrics but the implications of the underlying calculations are not well understood by stakeholders

Decision Making under Deep Uncertainty

- Decision Making under Deep Uncertainty (**DMDU**) methods incorporate concepts and techniques that help address the challenges of planning under climate change
- Shift away from statistics-based risk analysis
- Incorporate concepts and techniques that focus on vulnerability and robustness instead of risk
  - Model potential policies in a wide range of future conditions, including those more dire than observations; no need to choose what future to plan for up front
  - Analyze data to identify which conditions cause policy to be vulnerable across a range of metrics
  - Use analysis to decide which conditions we want a policy to be robust to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