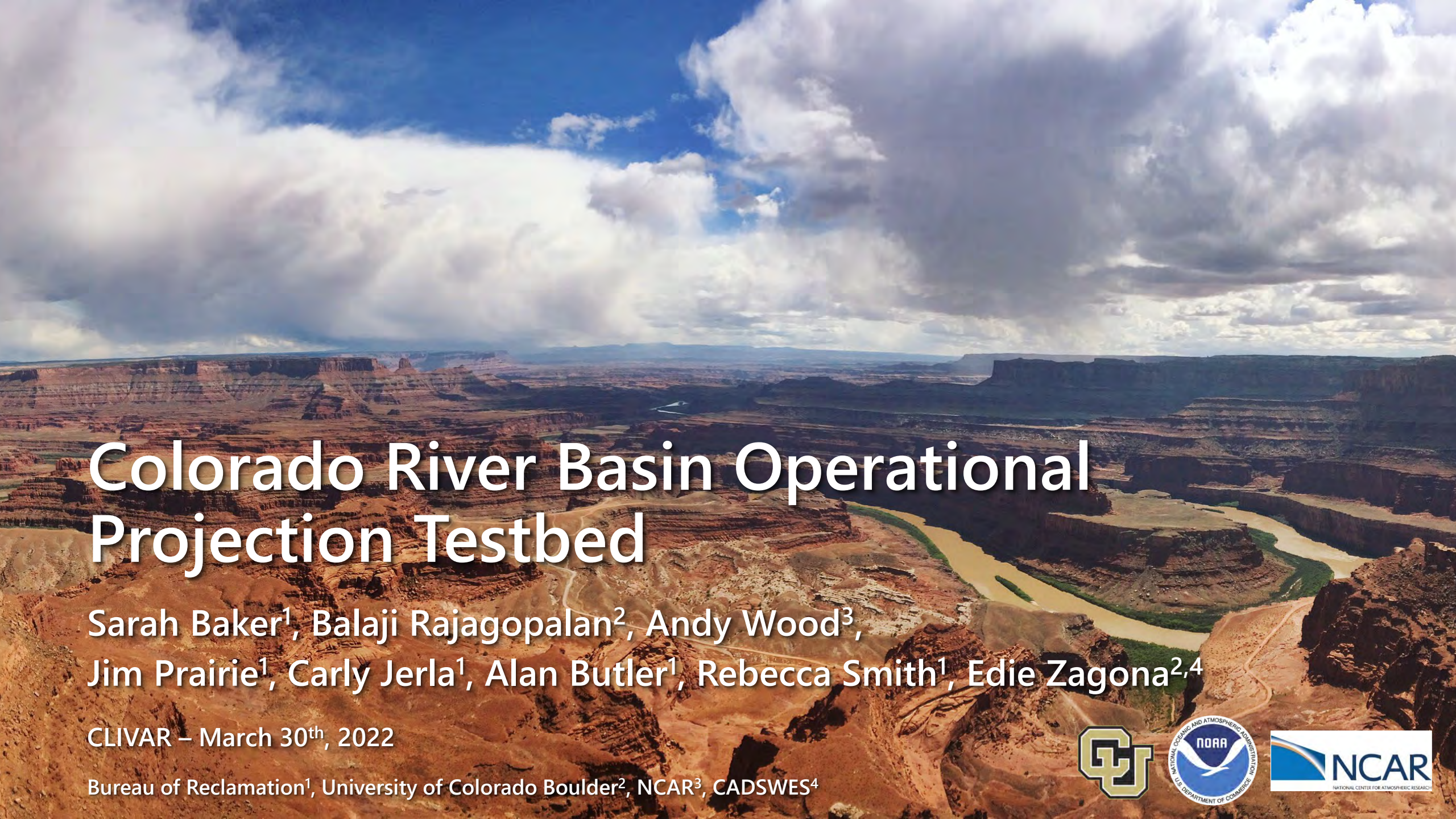

Colorado River Basin Operational Projection Testbed

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CLIVAR – March 30th, 2022

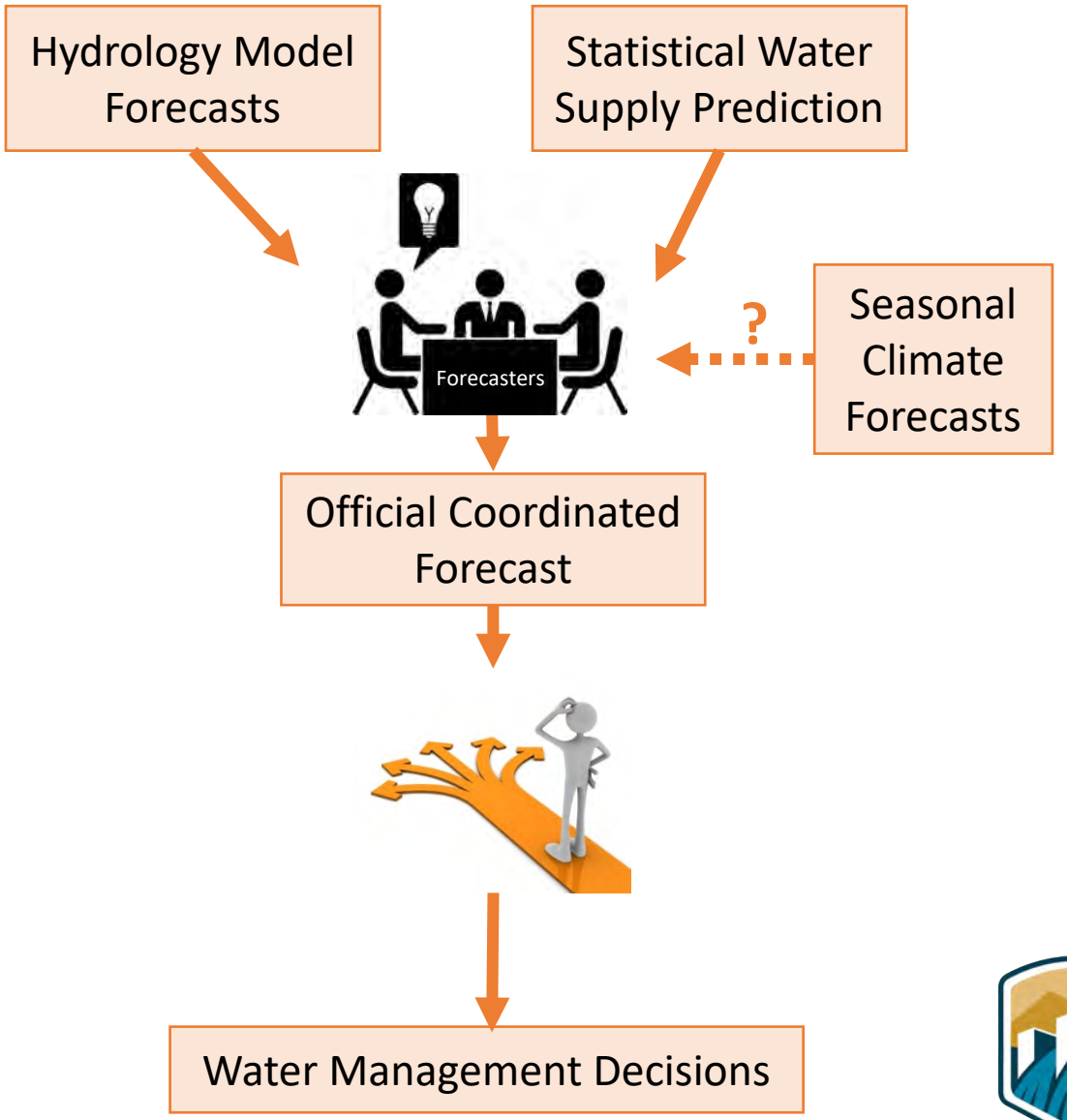
Bureau of Reclamation[1], University of Colorado Boulder[2], NCAR[3], CADSWES[4]

Reclamation Operational Modeling
Model Comparison

	Colorado River Mid-term Modeling System (CRMMS)		CRSS
	24-Month Study Mode (Manual Mode)	Ensemble Mode (Rule-based Mode)	
Primary Use	AOP tier determinations and projections of current conditions	Risk-based operational planning and analysis	Long-term planning, comparison of alternatives
Simulated Reservoir Operations	Operations input manually	Rule-driven operations	
Probabilistic or Deterministic	Deterministic – single hydrologic trace	Deterministic OR Probabilistic 30 (or more) hydrologic traces	Probabilistic – 100+ traces
Time Horizon (years)	1 - 2	1 - 5	1 - 50
Upper Basin Inflow	Unregulated forecast, 1 trace	Unregulated ESP forecast, 30 traces	Natural flow; historical, paleo, or climate change hydrology
Upper Basin Demands	Implicit, in unregulated inflow forecast		Explicit, 2016 UCRC assumptions
Lower Basin Demands	Official approved or operational		Developed with LB users

Streamflow Forecasting

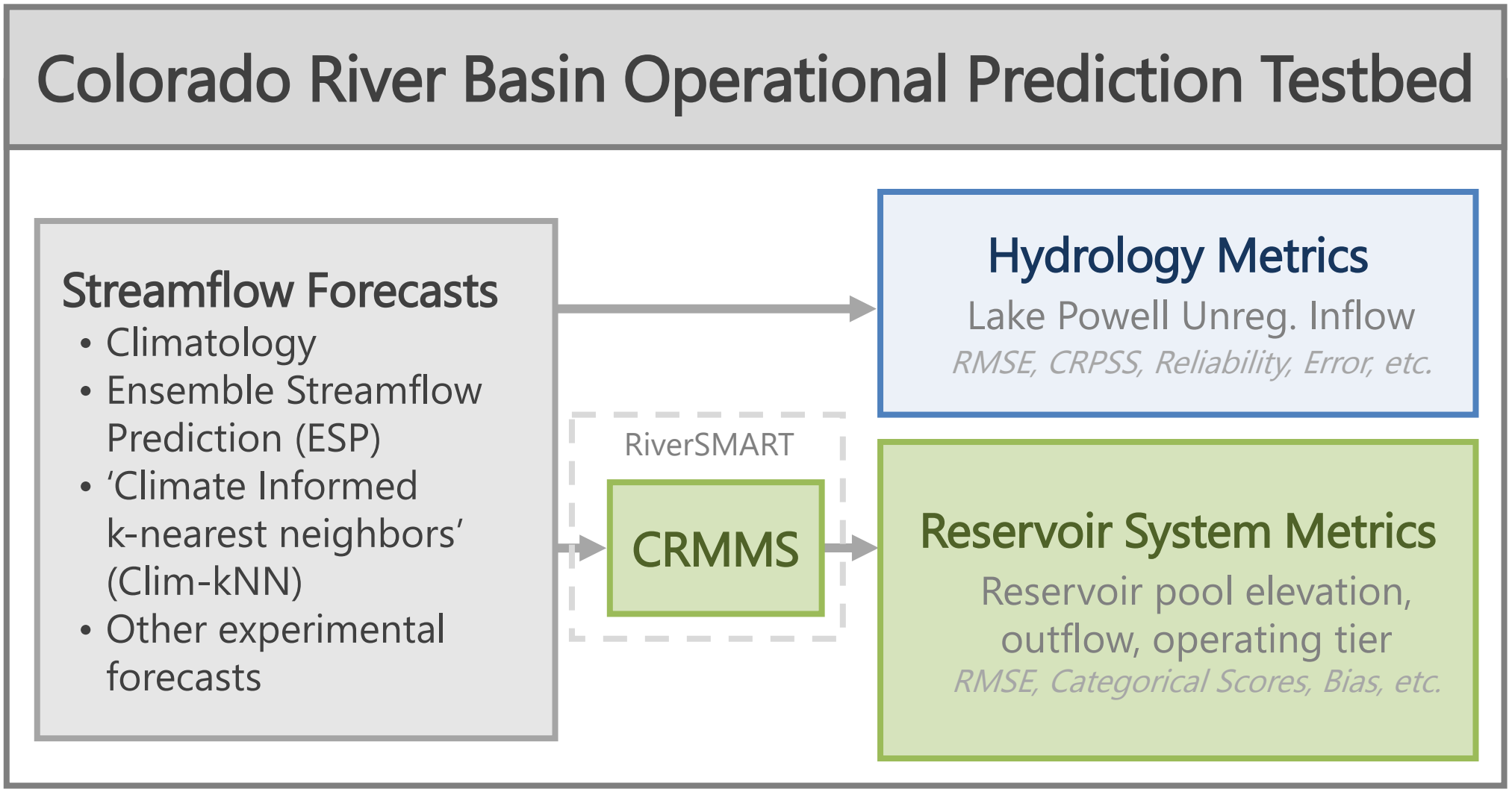
- Streamflow forecasts are important inputs to operations and planning models to project reservoir operations, as well as useful to agricultural, municipal, and recreation water users
- Most operational streamflow forecasts used by water managers are produced by River Forecasting Centers (RFCs)
- Streamflow forecasts are not informed by climate forecasts in a procedural way
- 'Official' streamflow forecasts are sometimes nudged based on the seasonal climate forecasts by the forecaster, but this is up to their discretion



Objectives

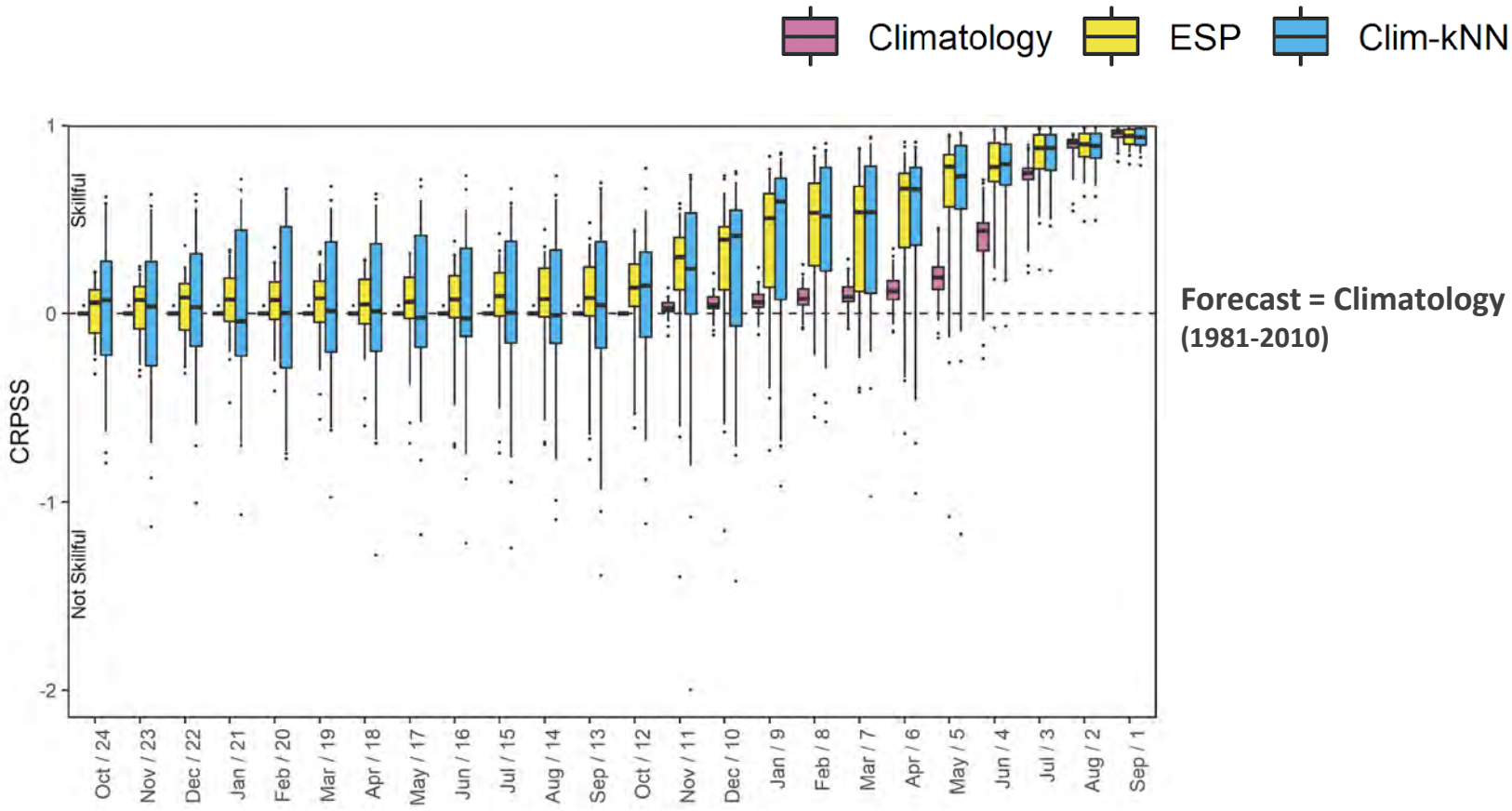
1. Create a testbed framework and establish a protocol for testing the performance of streamflow forecasts and modelled operational projections in the Colorado River Basin (CRB).
2. Compare current streamflow forecasts and reservoir operational projections with the Colorado Basin Streamflow Forecast Testbed, which uses Reclamation's Colorado River Mid-term Modeling System (CRMMS).
3. Use the testbed to run and compare experimental streamflow forecasting technique in the Upper Colorado River Basin.

Testbed Framework



Water Year Lake Powell Unreg. Inflow

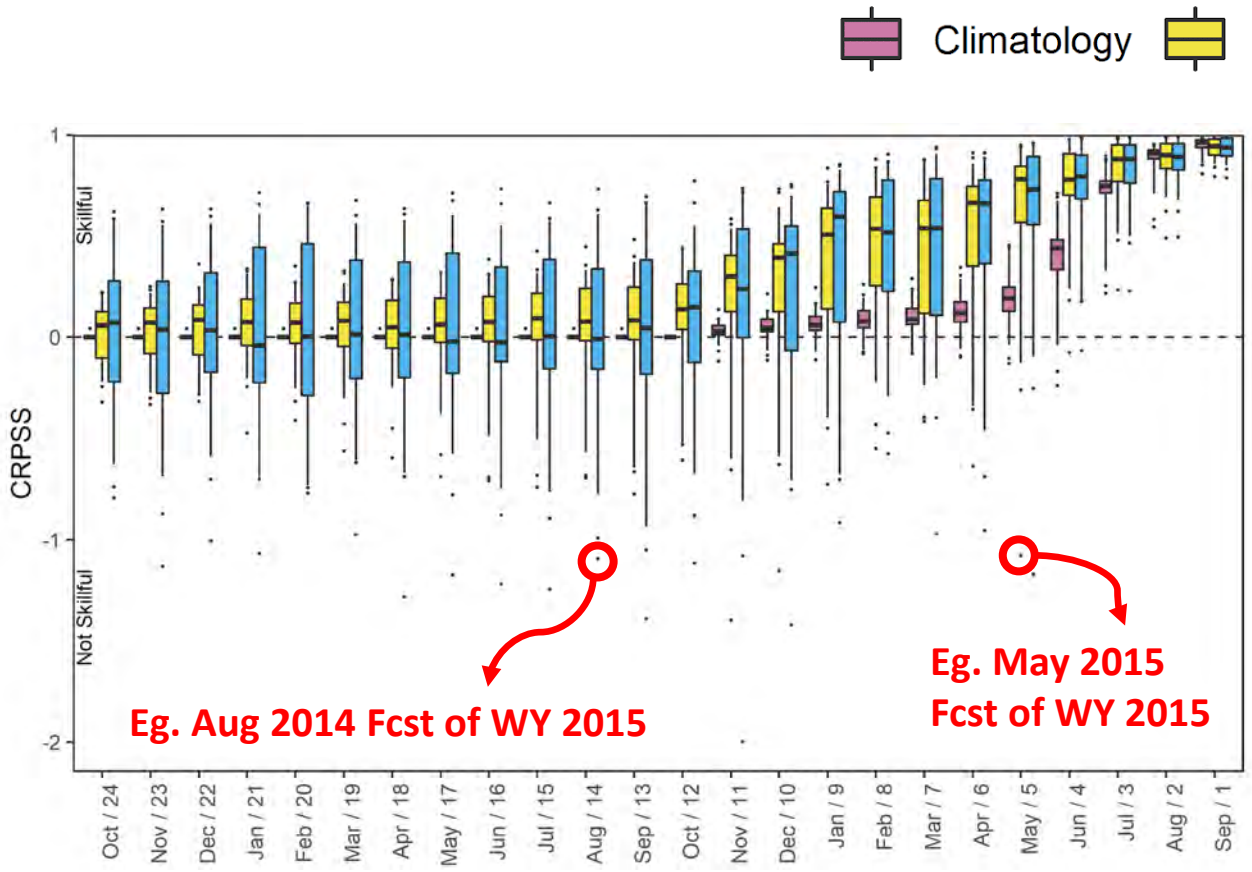
Forecasts from 1982-2016



Forecast = Climatology
(1981-2010)

Water Year Lake Powell Unreg. Inflow

Forecasts from 1982-2016



Forecast = Climatology
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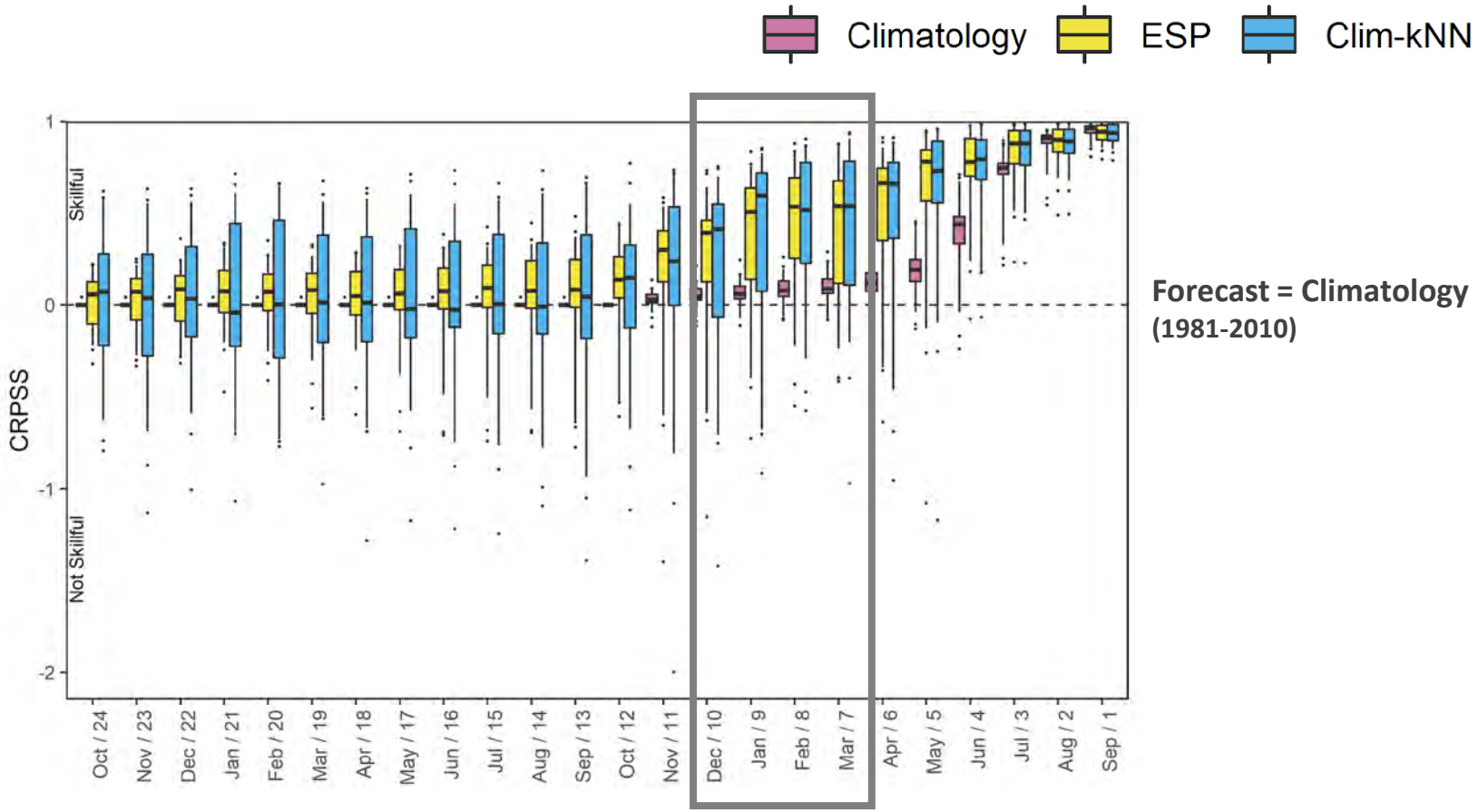
Water Year Lake Powell Unreg. Inflow

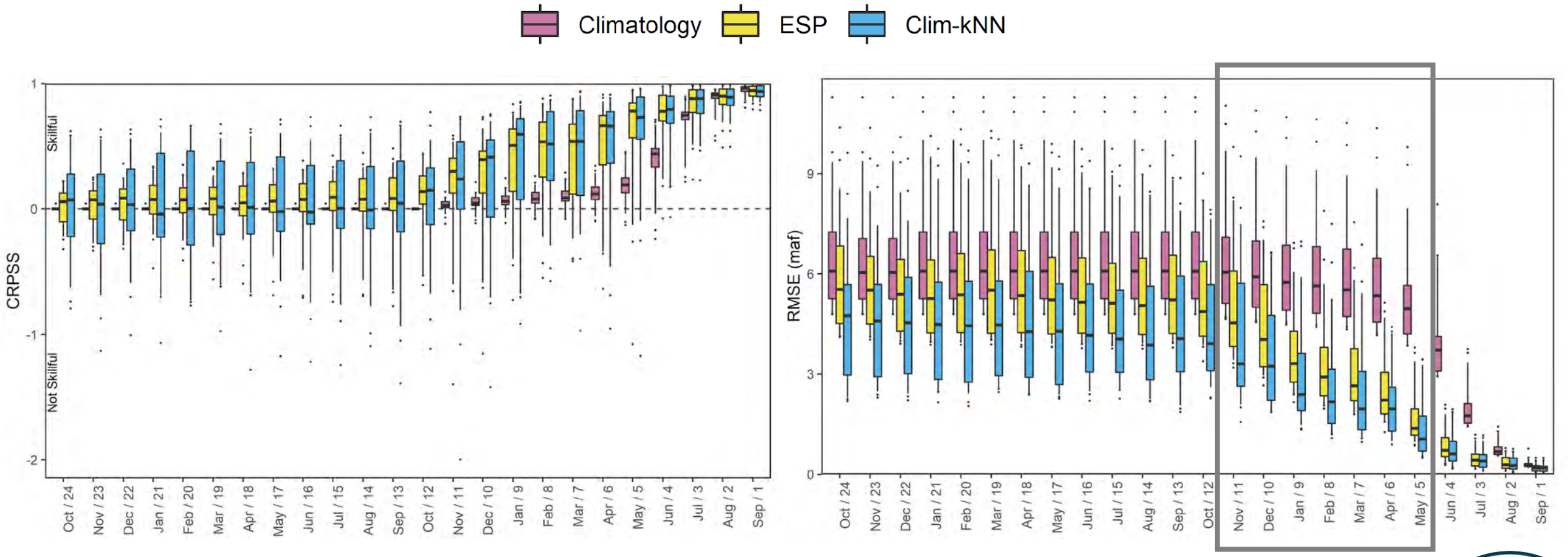
Forecasts from 1982-2016



Forecast = Climatology
(1981-2010)

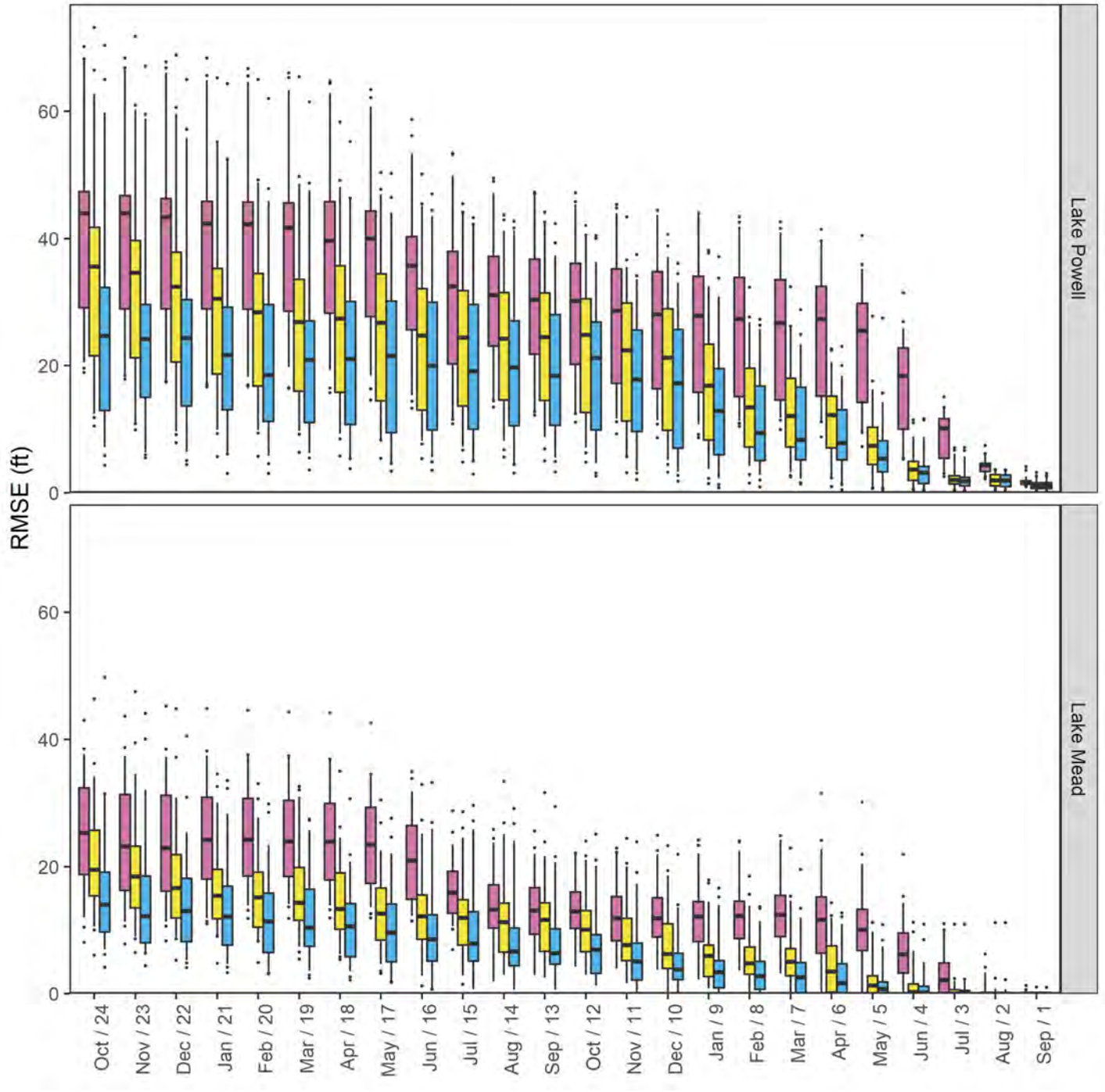
Water Year Lake Powell Unreg. Inflow

Forecasts from 1982-2016



End-of-Water Year Pool Elevation

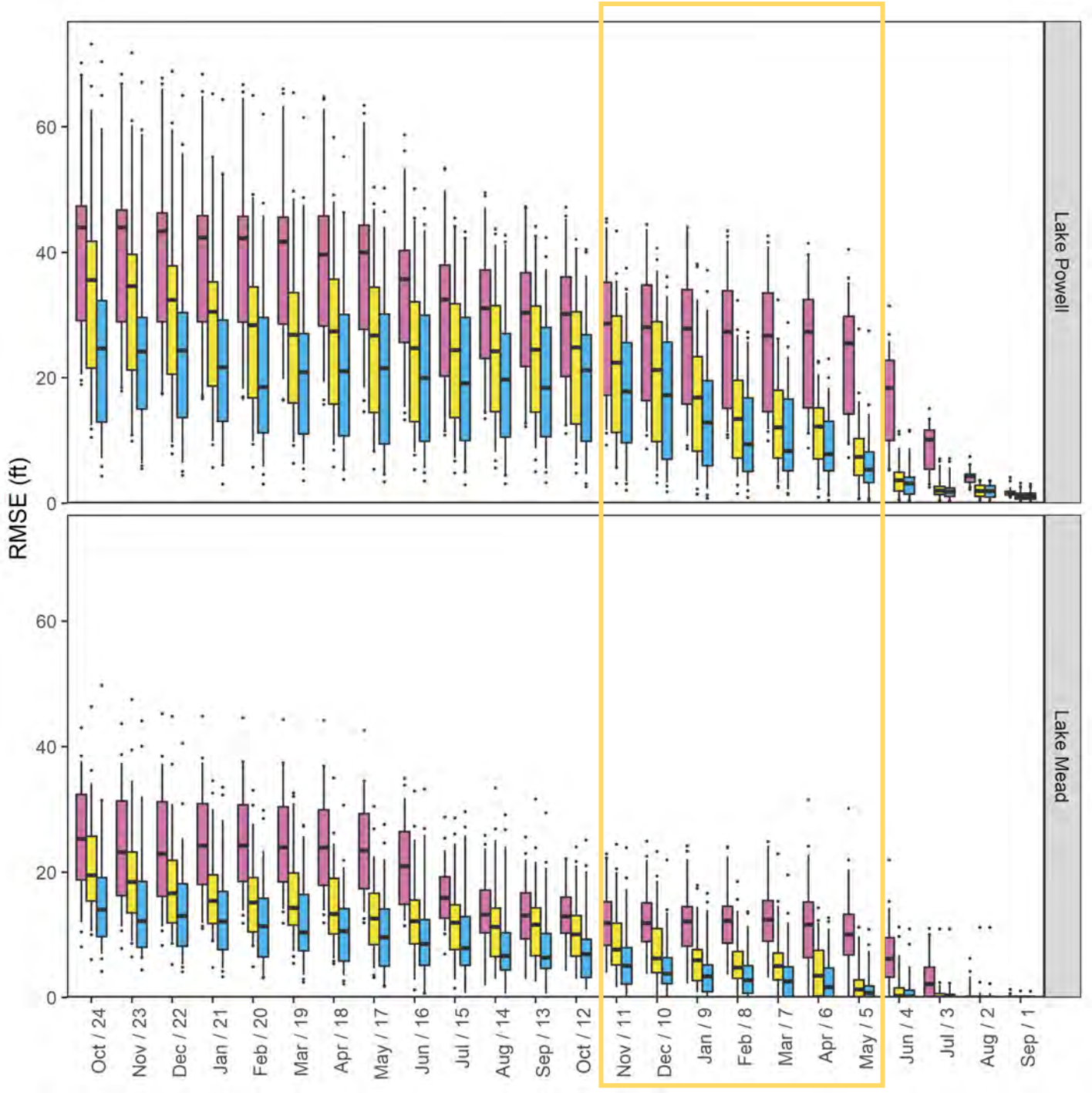
Forecasts from 1982-2016



End-of-Water Year Pool Elevation

Forecasts from 1982-2016

Climatology ESP Clim-kNN



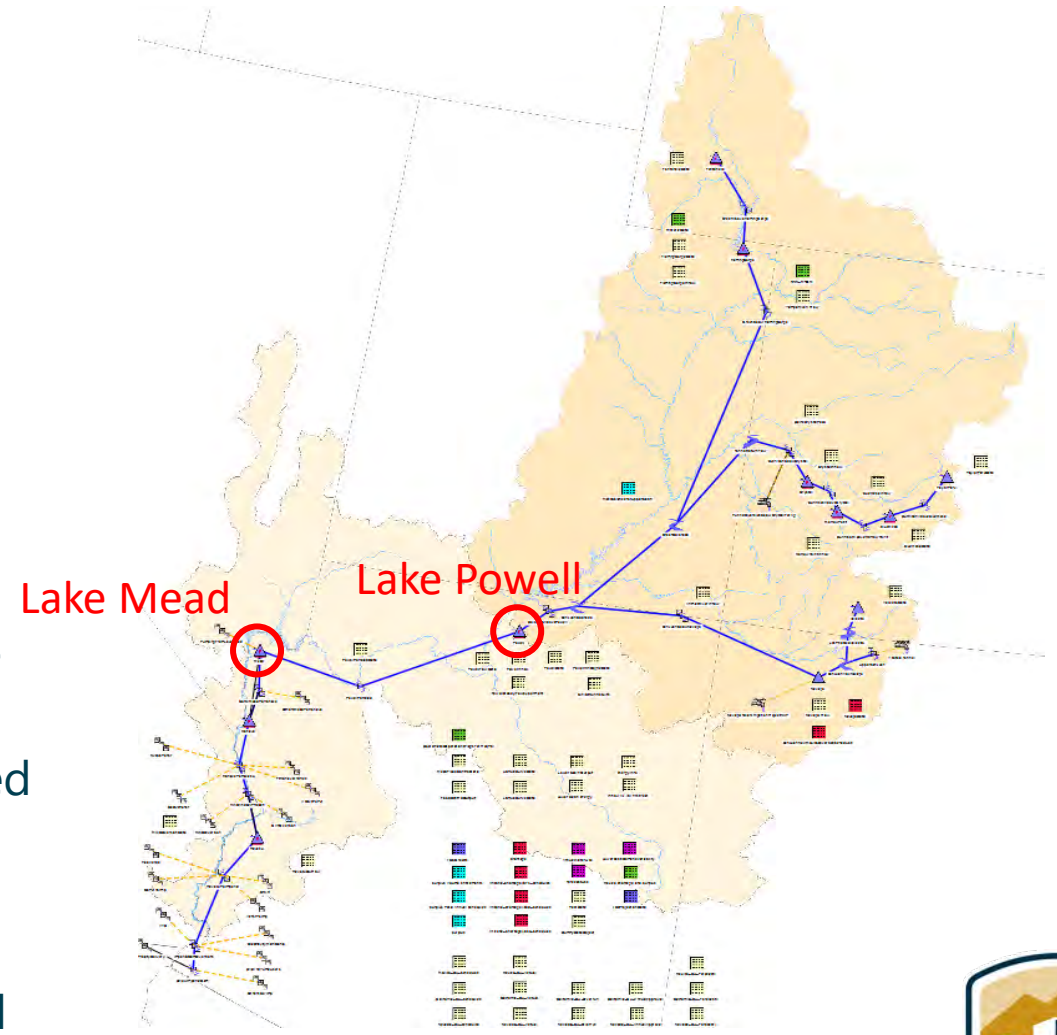
Conclusion

- Colorado River Basin Operational Projection Testbed provides a foundation for the systematic evaluation of inflow forecasts that represent the Upper Basin hydrologic and basin-wide operational projections
- Illustrates opportunities for improvements in skill and reduction in error in streamflow forecasts
- Enhanced streamflow forecasts translated into improved projected operations at Lake Powell and Lake Mead
- In the future, the testbed will be used to assess other experimental streamflow forecasts as they become available


Questions ?
BUREAU OF
RECLAMATION

CRMMS: Colorado River Mid-term Modeling System

- Reclamation's mid-term risk-based operational planning and analysis model of the Colorado River Basin
- RiverWare model that simulates operations at 12 reservoirs in the basin
- Monthly rule-driven operations of the 2007 Interim Guidelines and other treaties, plans, minutes and agreements
- Upper Basin streamflow forecasts are provided by the Colorado Basin RFC (CBRFC)
  - Ensemble Streamflow Prediction (ESP) forecasts are used in CRMMS operationally
  - Hindcasts and forecasts were provided by the CBRFC from 1981-2016
  - 30 traces of monthly streamflow from hydrology model forced with temperature and precipitation timeseries from the period of record



Lake Powell & Lake Mead
Operational Diagrams and Current Conditions*

Lake Powell			Lake Mead		
Elevation (feet)	**Operation According to the Interim Guidelines**	**Live Storage (maf)[1]**	**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	1,220	**Flood Control Surplus or Quantified Surplus Condition** Deliver > 7.5 maf	25.9
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)	1,200 (approx.)[2]	**Domestic Surplus or ICS Surplus Condition** Deliver > 7.5 maf	22.9 (approx.)[2]
			1,145		15.9
			1,105	**Normal or ICS Surplus Condition** Deliver ≥ 7.5 maf	11.9
3,575	**Mid-Elevation Release Tier** Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	9.5	1,062.18 3/27/22	**Shortage Condition** Deliver 7.167[4] maf	8.59 3/27/22
			1,050		7.5
3,525		5.9		**Shortage Condition** Deliver 7.083[5] maf	
3,523.53 3/27/22	**Lower Elevation Balancing Tier** Balance contents with a min/max release of 7.0 and 9.5 maf	5.84 3/27/22	1,025		5.8
3,490		4.0	1,000	**Shortage Condition** Deliver 7.0[6] maf Further measures may be undertaken[7]	4.3
3,370		0	895		0

Diagram not to scale

[1] Acronym for million acre-feet

[2] This elevation is shown as approximate as it is determined each year by considering several factors including Lake Powell and Lake Mead storage, projected Upper Basin and Lower Basin demands, and an assumed inflow.

[3] Subject to April adjustments which may result in a release according to the Equalization Tier

[4] Of which 2.48 maf is apportioned to Arizona, 4.4 maf to California, and 0.287 maf to Nevada

[5] Of which 2.40 maf is apportioned to Arizona, 4.4 maf to California, and 0.283 maf to Nevada

[6] Of which 2.32 maf is apportioned to Arizona, 4.4 maf to California, and 0.280 maf to Nevada

[7] Whenever Lake Mead is below elevation 1,025 feet, the Secretary shall consider whether hydrologic conditions together with anticipated deliveries to the Lower Division States and Mexico is likely to cause the elevation at Lake Mead to fall below 1,000 feet. Such consideration, in consultation with the Basin States, may result in the undertaking of further measures, consistent with applicable Federal law.

*The blue shaded region indicates the operating tier for the current water/calendar year for Lake Powell and Lake Mead, respectively.

Streamflow Forecasts

All streamflow forecast datasets were available on the eighth of the month for each month of water years 1982-2016

1. Climatology (1981-2016)

- Historical streamflow was used as a forecasting baseline to determine whether forecasts perform better than and experimental forecast
- Climatology ensembles (29 or 30 traces) were assembled from historical flows (water years 1981-2010), with each ensemble member being a historical flow sequence from a given year starting on the date of the forecast and extending through the forecast lead time

2. ESP (1981-2016)

- Current official streamflow forecasting method
- 30-member ensemble reforecasts provided by the Colorado Basin RFC (Sac-SMA calibrated with 1981-2010 data)

3. Clim-kNN (1981-2016)

- Trace weighting method for ESP informed by NMME 1-month and 3-month climate forecasts and antecedent flow
- For further information about Clim-kNN see: *Baker, S. A., B. Rajagopalan, and A. W. Wood. 2021. "Enhancing Ensemble Seasonal Streamflow Forecasts in The Upper Colorado River Basin Using Multi-Model Climate Forecasts." Journal of the American Water Resources Association (JAWRA) 57 (6): 906-922. https://doi.org/ 10.1111/1752-1688.12960*