CALIFORNIA DEPARTMENT OF WATER RESOURCES

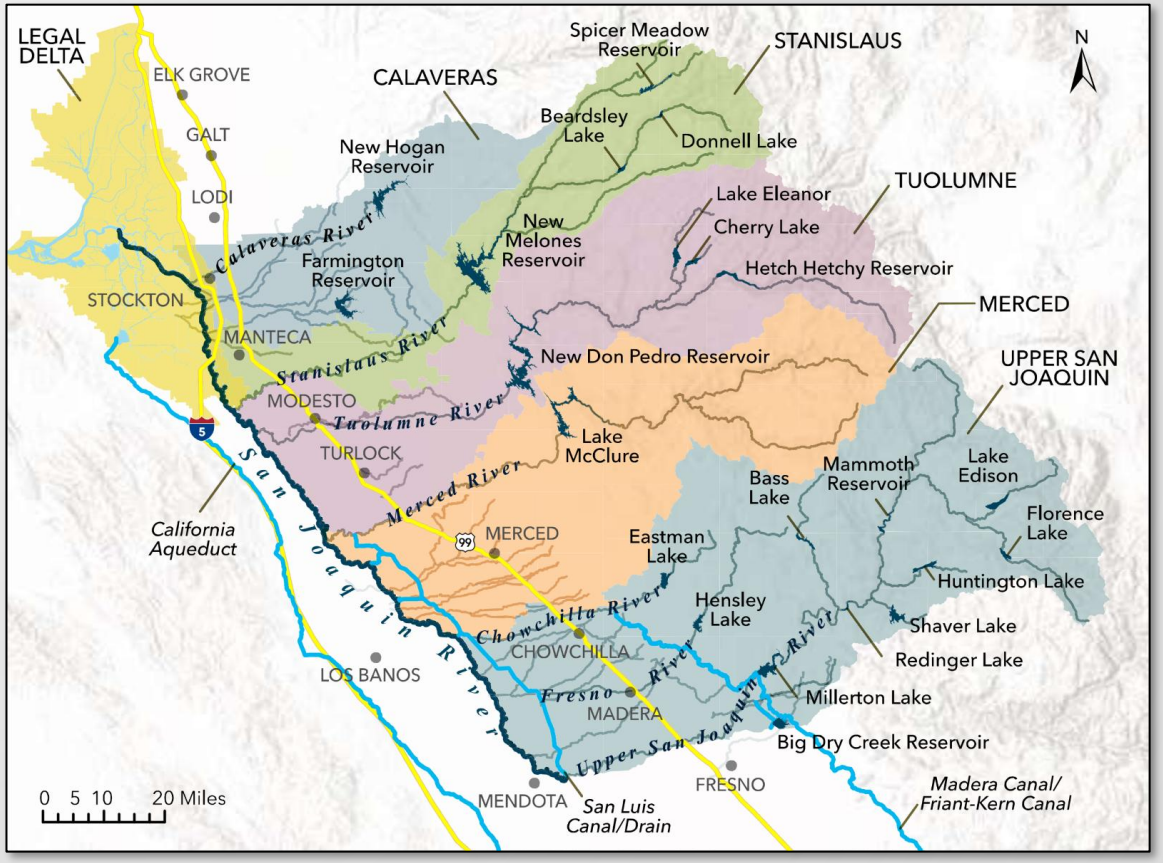
FIRO-MAR Operations with 1-to-7-day Synthetic Ensemble Forecast

2025 CWEMF Annual Meeting

May 13, 2025

FIRO-MAR Operations Background

- Initially developed for Merced River Watershed Flood-MAR Pilot Study
  - Applied for Lake McClure
  - Based on perfect forecast
- Improved for the San Joaquin Flood-MAR Watershed Studies
  - Extended to seven reservoirs within the study area
  - Added synthetic ensemble forecast to represent uncertainty

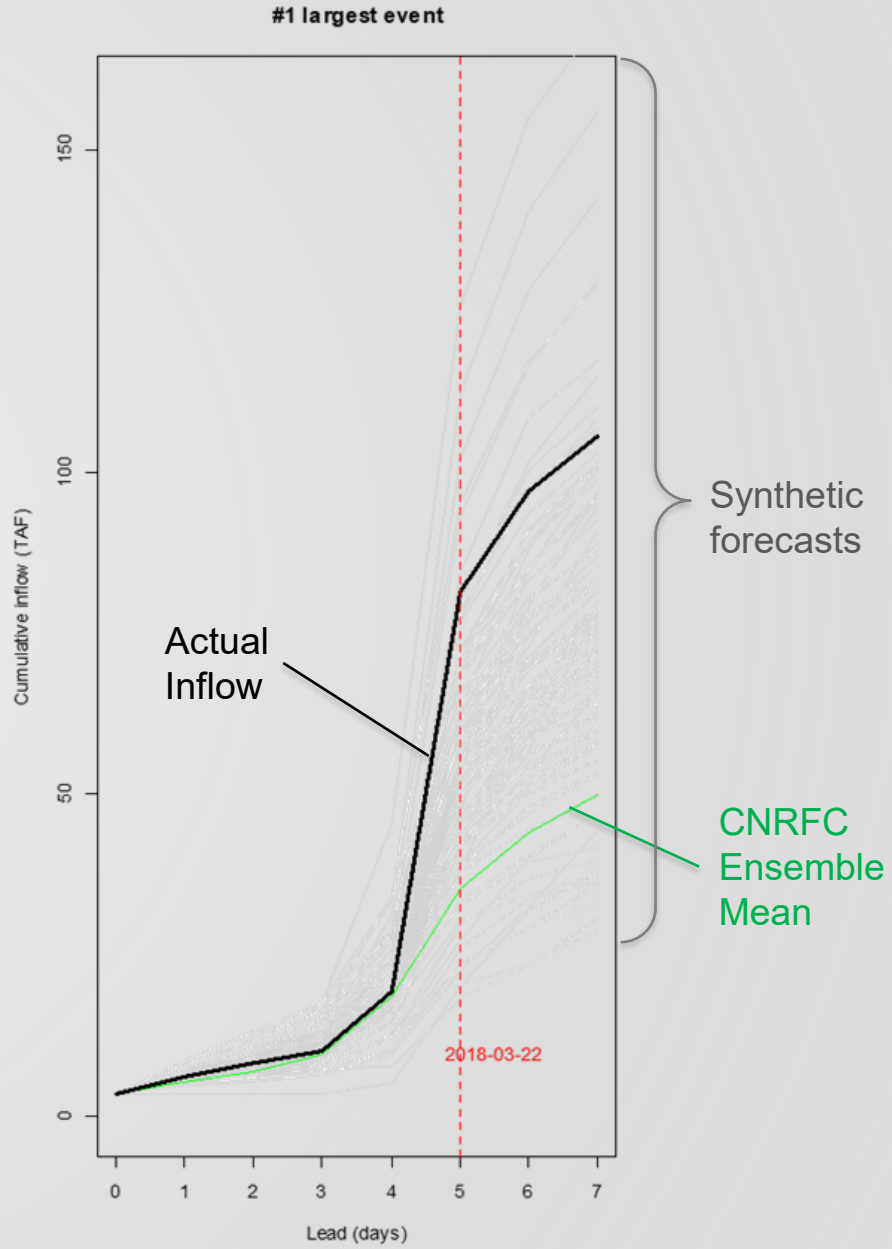


Components of FIRO-MAR Modeling

- Ensemble Forecast
  - Based on synthetic forecast error model to represent uncertainty
- FIRO Space
  - Allows utilization of Flood Space with FIRO operations
- Ensemble Forecast Operations (EFO)
  - 1-7-day risk-based release decision
- Integration of FIRO with MAR
  - Adds MAR release (limited to daily recharge capacity)
  - Modifies flood-control release

Synthetic Forecast Error Model

- Can be applied to any inflow timeseries
- Based on historically observed forecast uncertainty
  - CNRFC ensemble mean forecast (2013-2022)
- Synthetic forecast error model components:
  - 1-7-day lead
  - Conditional mean (*observation → forecast*)
  - Heteroskedasticity (*larger forecasts → larger variance*)
  - VAR = 1 (*correlation of error with previous forecast error*)
  - Correlated residuals (*correlation of errors across leads*)



Brodeur and Steinschneider (2021). A multivariate approach to generate synthetic short-to-medium range hydro-meteorological forecasts across locations, variables, and lead times. Water Resources Research. https://doi.org/10.1029/2020WR029453

Implementation of Ensemble Forecast in HEC-ResSim

Pre-process synthetic forecast as inflow volume for 1-7-day lead

Prepare SQLITE database with the ensemble forecasts

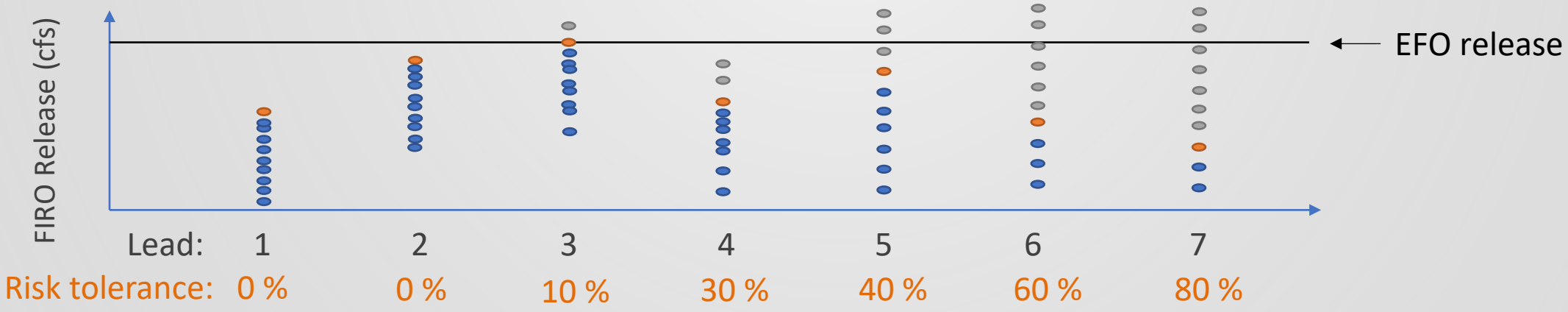
Develop EFO Logic scripting to use ensemble forecasts and calculate FIRO Release

Install TS_Ensemble Reader plugin (developed by HEC)

Ensemble Forecast Operations (EFO) Logic

- First, we specify a risk tolerance for each lead time
- For each Lead (1-to-7-day)
  - For each ensemble forecast member (n=10)
    - FIRO Release $_{L,n}$ = (Forecast Inflow + Storage – Top of FIRO) / Lead Time
- Order release and select one for each lead time based on risk tolerance
- Across all leads, select max release
  - EFO Release = Max (FIRO Release$_{L(n\text{-}risk)}$)
- EFO Release is capped by operational constraints downstream

Conceptual Demonstration



FIRO Space Determination

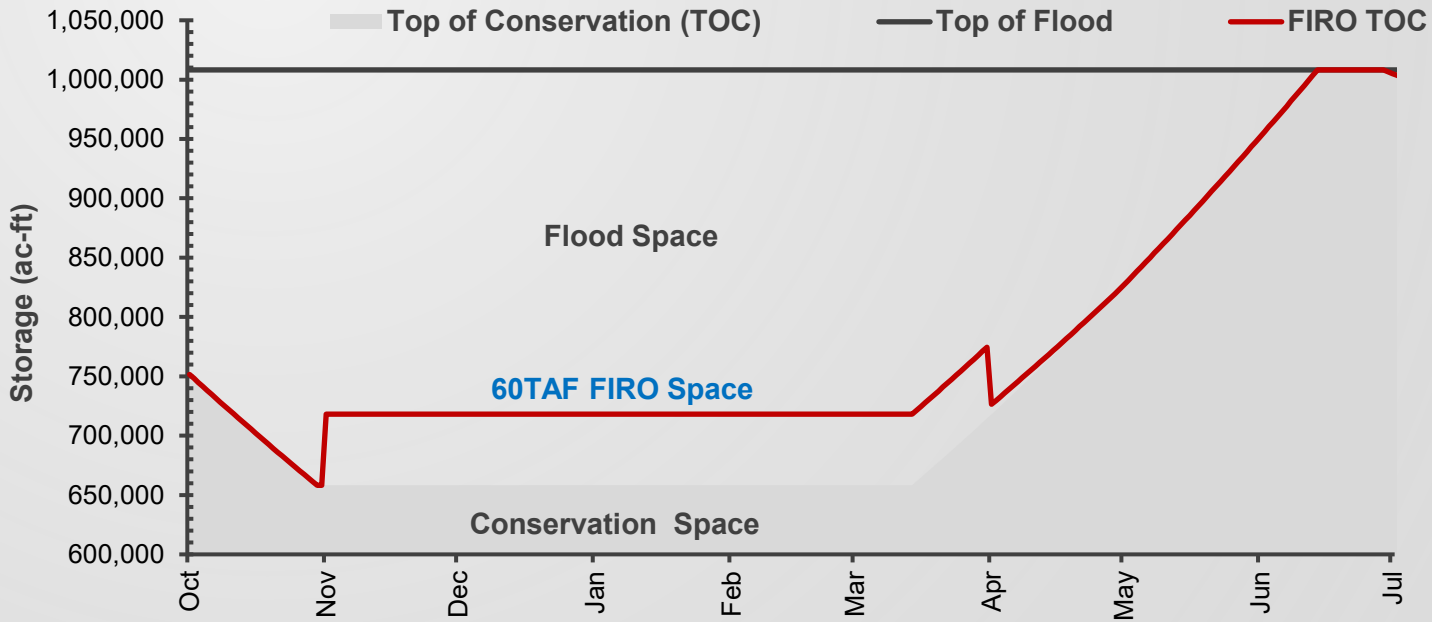
A FIRO space was developed considering the following guidelines:

- Flood release volume over five-day period at downstream channel capacity
- Size of the reservoir storage (gross) – 5% percent of storage
- Size of the flood space – around 10% to 20% of flood space, maximum of 50%

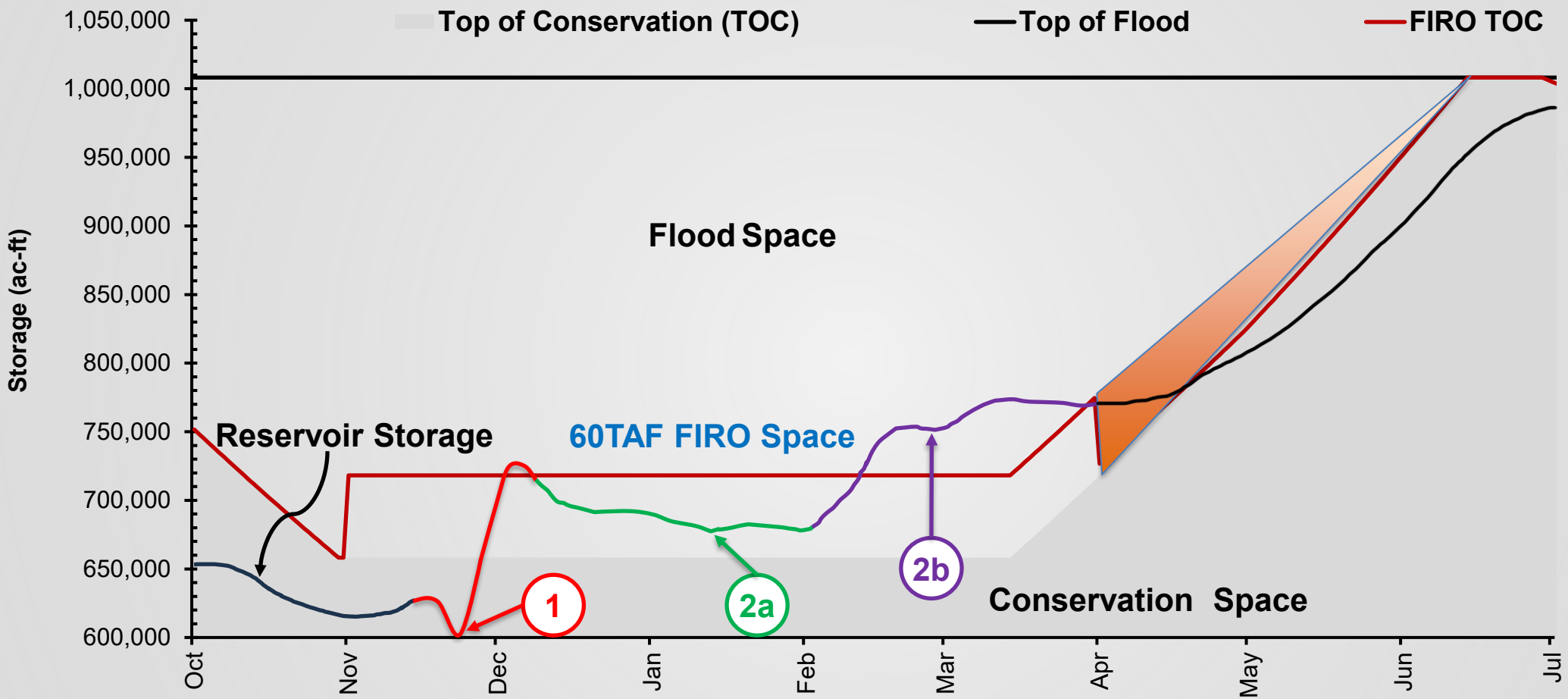
Final FIRO Space developed through repeated simulation and testing

Lake McClure Example

- Merced River channel capacity is 6,000 cfs
- FIRO Space = 6,000 cfs x 5 days = 60 TAF
- About 6% of total storage
- About 17% of flood space
- Tested under existing and climate change conditions
- FIRO Space Determination – 60 TAF



Integrating FIRO and MAR at Lake McClure



1 Conservation Pre-Release

2a MAR Release in FIRO Space

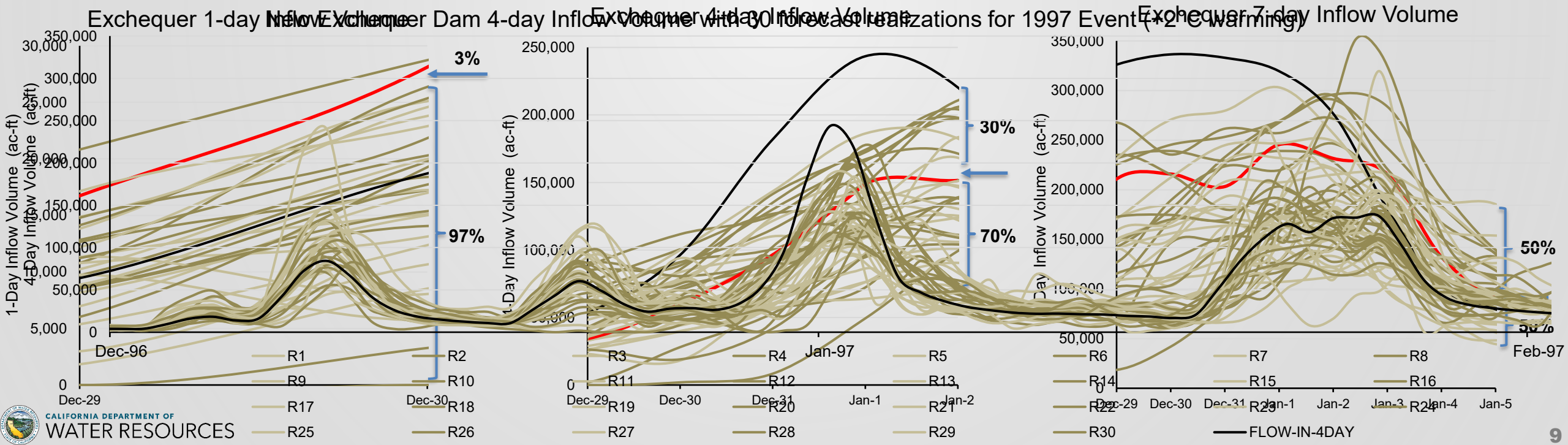
2b MAR + Flood Control Release

Application

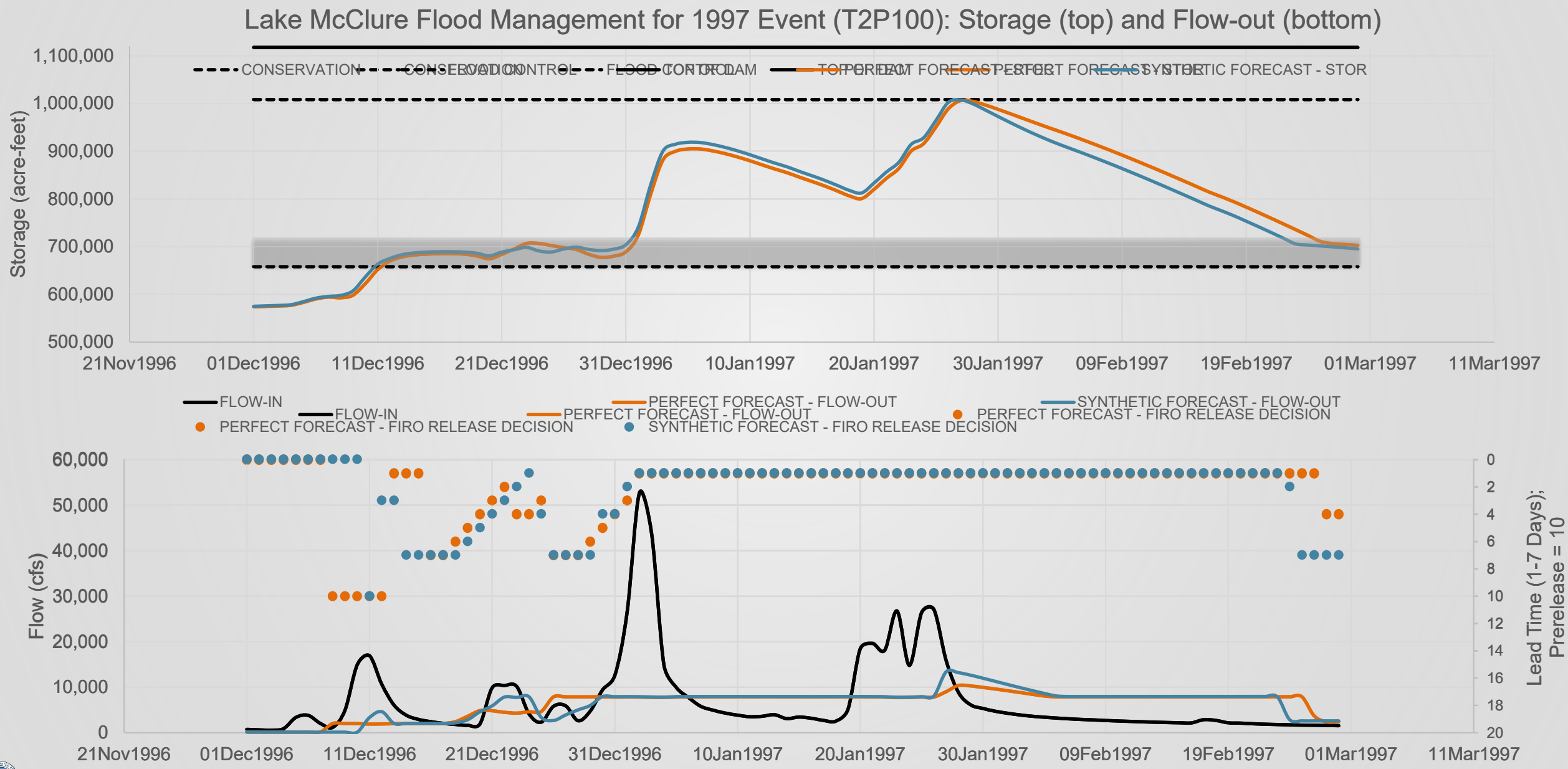
- FIRO operations are driven by the risk tolerance curve
- A release is calculated for each member of the ensemble
- Risk tolerance levels correspond to non-exceedance levels of the ensemble calculated releases
- Uncertainty in the forecast grows with lead-time; therefore more risk is tolerated at longer lead times

New Exchequer 1997 Event (+2°C warming)

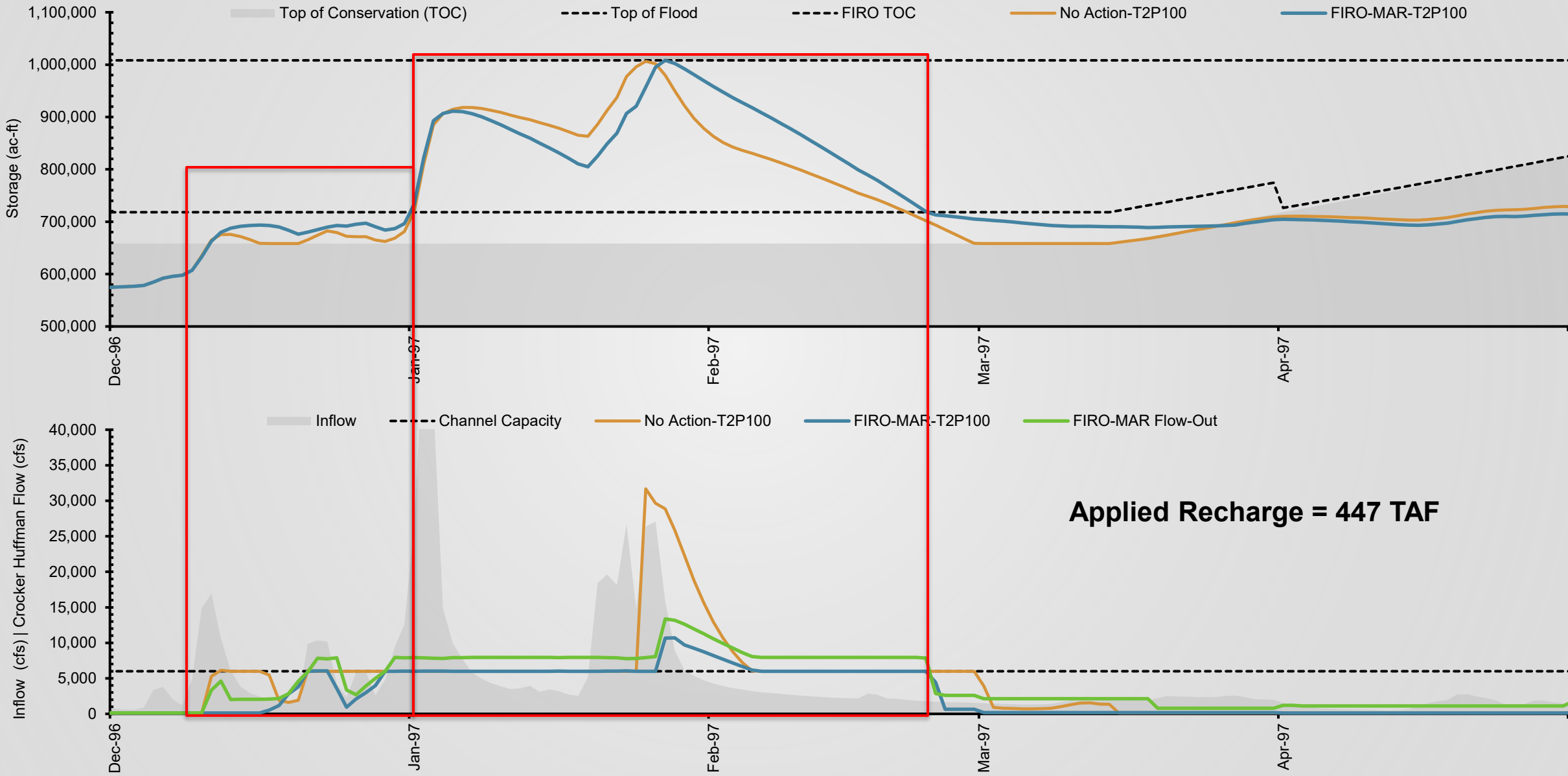
Lead-Time (days)	Risk Tolerance (%)	EFO Release (cfs)
1	3%	0
2	10%	4,650
3	20%	6,767
4	30%	9,126
5	40%	8,614
6	50%	8,149
7	50%	8,390



Performance with Forecast Uncertainty

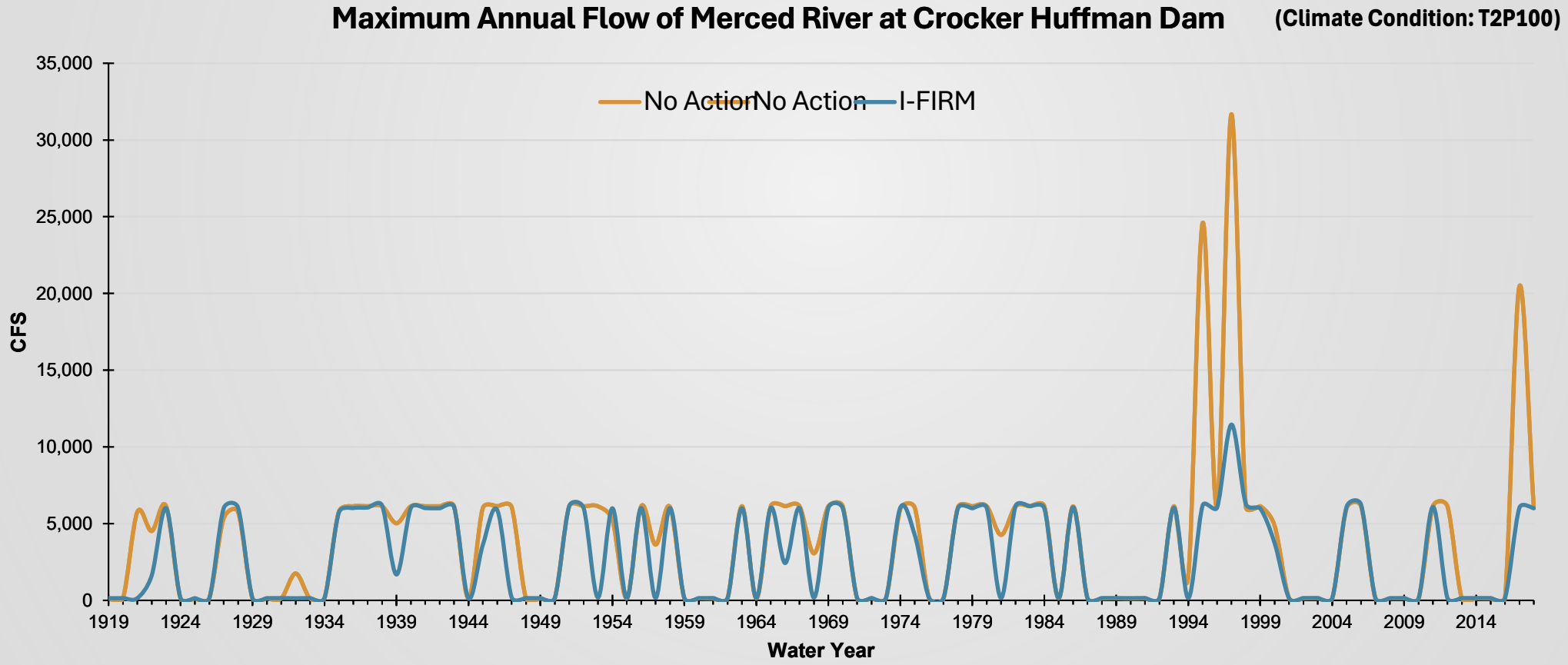


Lake McClure Flood Management for 1997 (+2°C warming)



Flood Management: Merced River

Reservoir re-operation paired with FIRO significantly reduces the frequency and intensity of flood flows compared to Baseline.



Potential Improvements

- Improve the representation of forecast error by using the full CNRFC ensemble (as opposed to the mean only)
- Extend synthetic forecast beyond 7 days with 30+ year hindcast
- Streamline the data management and HEC programming for simulating the EFO in HEC-ResSim
- Further exploration of design of FIRO Space and the risk tolerance for each reservoir
- Consider any operational constraints downstream

Conclusions

- Uncertainty in the forecast can cause effect to the flood operations that can carry throughout the event
- Increased release capacity mitigates being encroached in flood space
- An opportunity to integrate flood management with other water management sectors
  - Banked FIRO storage can be repurposed for other objectives
  - Reduces flood risk downstream while building groundwater supply
  - Provides multi-sector benefits

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