Quantifying Uncertainties in Forecasts of Managed Temperature and Temperature Dependent Mortality in the Shasta-Sacramento River System

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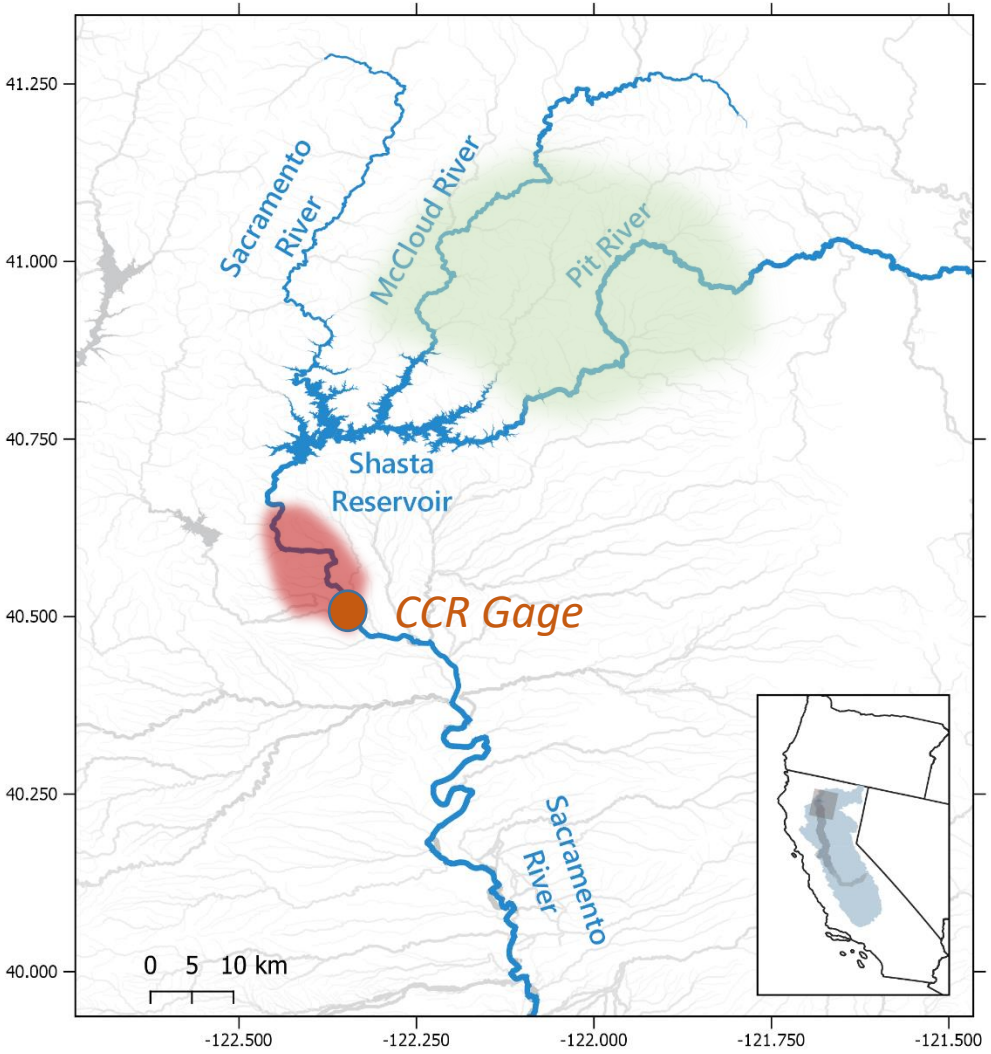
Outline

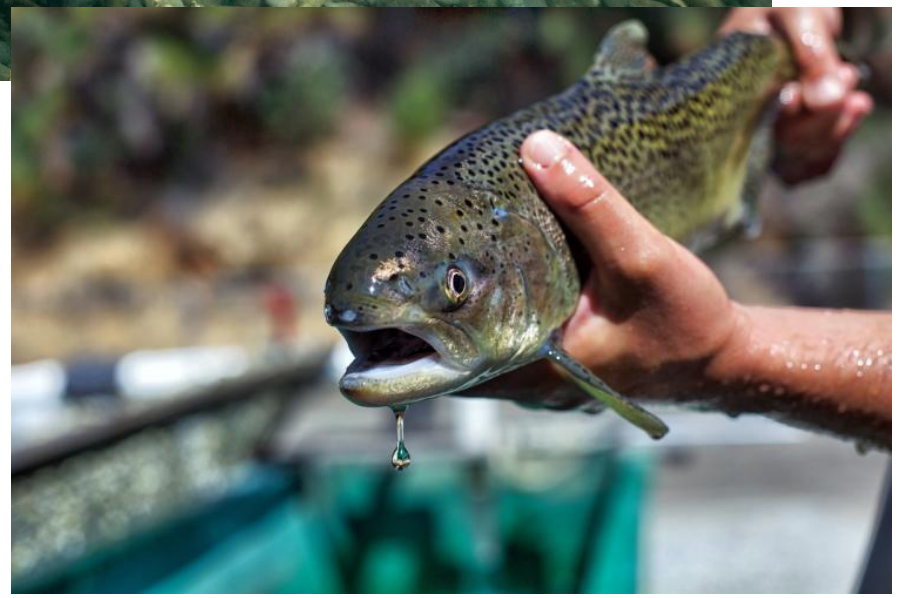
- Background:
  - Shasta Reservoir, Sacramento River, and salmon
- Forecasting context
  - Seasonal operations
- Uncertainties
  - Hydrology, meteorology
- Analysis

Background: Shasta Reservoir and Sacramento River



- Shasta Reservoir:
  - California's biggest (~4.5 MAF or 5615 MCM)
  - At north end of California's Central Valley
  - Impounds waters from three main tributaries
- Shasta and Keswick Dams block access to cold, spring-fed waters in these tributaries **historically used for salmon spawning**
- Spawning now occurs in the reaches of the Sacramento River just below the dams
- Temperatures managed to control points on the river, like the **Clear Creek confluence (CCR) gage**

Background: Endangered Salmon

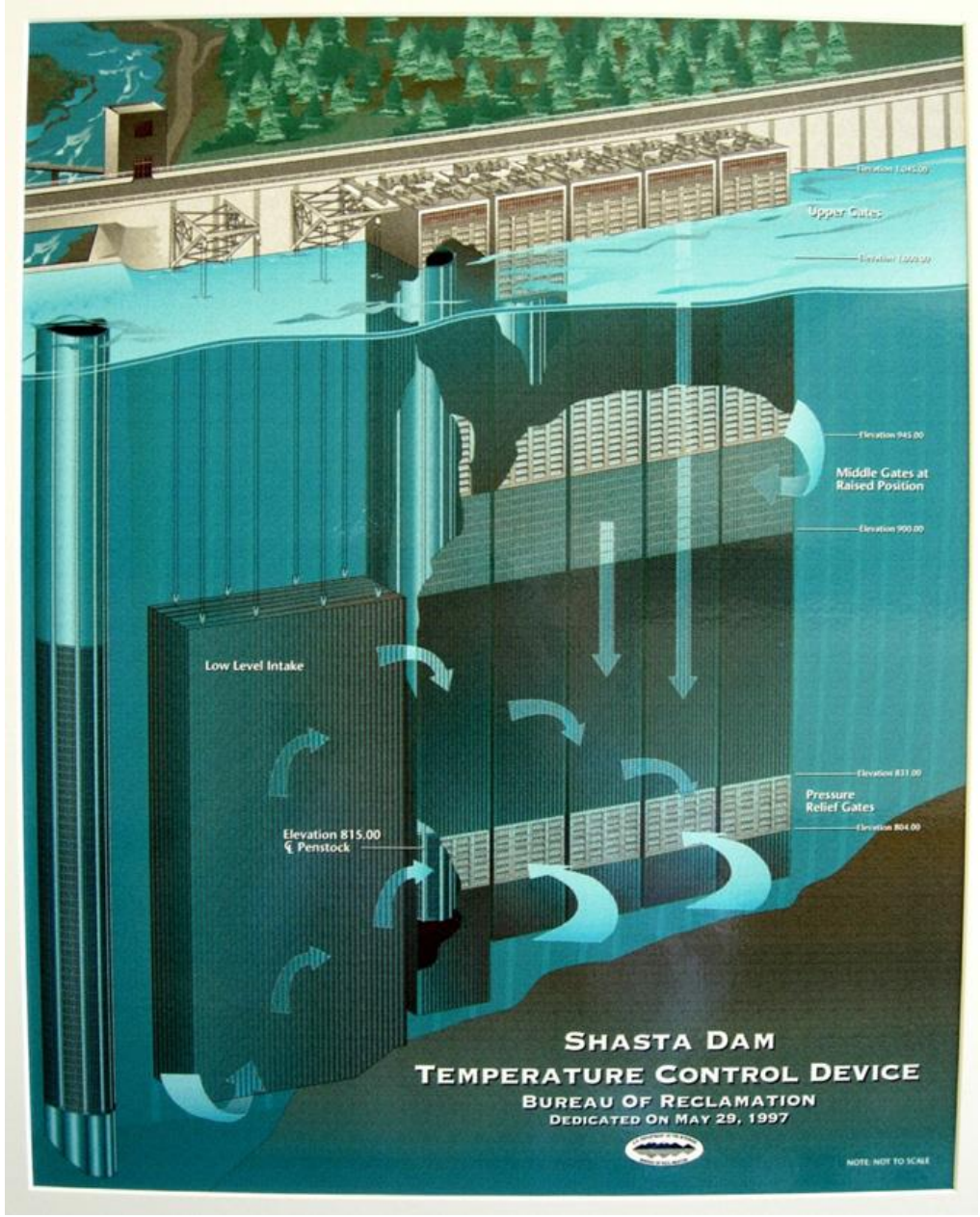


- Four main runs of Chinook salmon return to Central Valley rivers each year
- Winter Run Chinook (WRC) is critically endangered and spawns only in the Sacramento River
- Despite the name, WRC spawn in the summer
- Egg survival affected by thermal control from Shasta Reservoir
  - Quantified as Temperature Dependent Mortality (TDM)

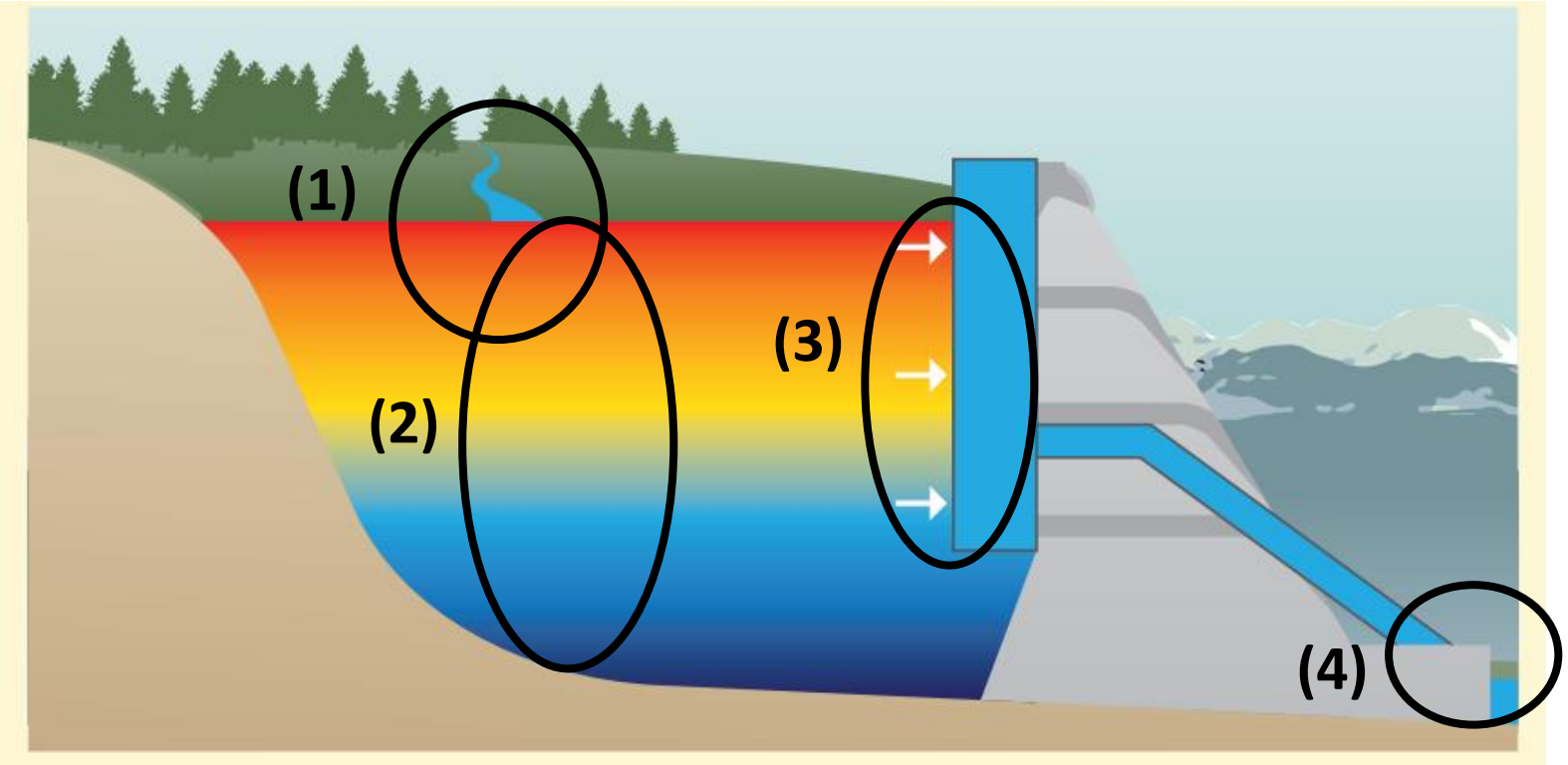
Background: Temperature Management

Shasta Temperature Control Device (TCD)

- Installed in 1997
- Provides 4 levels for selective withdrawal and blending
- Operated to meet downstream temperature targets through the summer



Background: Why is there uncertainty in forecasts of managed water temperatures?

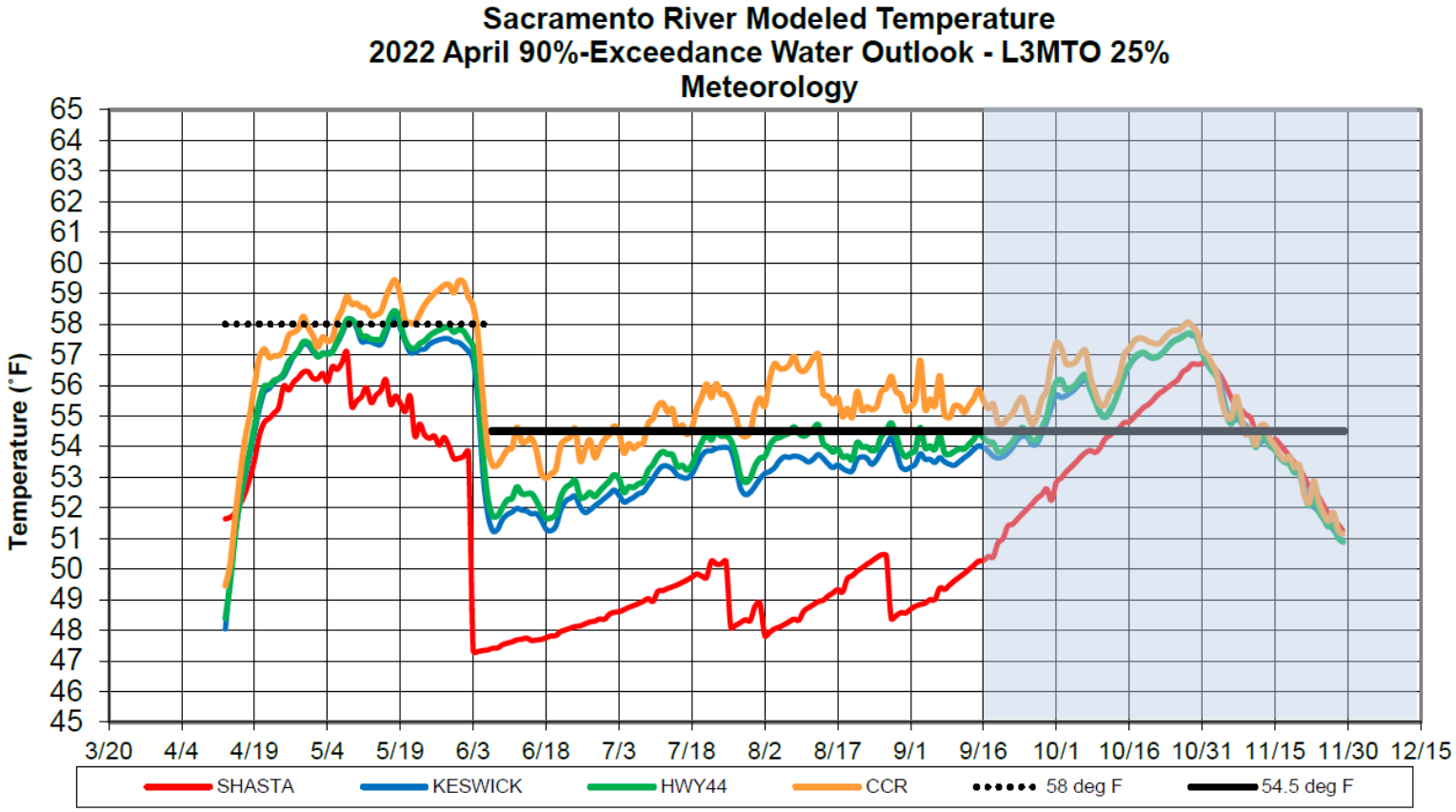


*Source: "*Water Temperature Management in Reservoir-River Systems through Selective Withdrawal"
https://www.usbr.gov/mp/bdo/docs/cvp-wtm-selective-withdrawal-2017-09.pdf

1. Inflow is uncertain – determines storage and water level in reservoir
2. Storage, inflow and meteorology affect thermal stratification (timing and strength)
3. Discrete (imprecise) blending mechanisms
4. Meteorological effects downstream

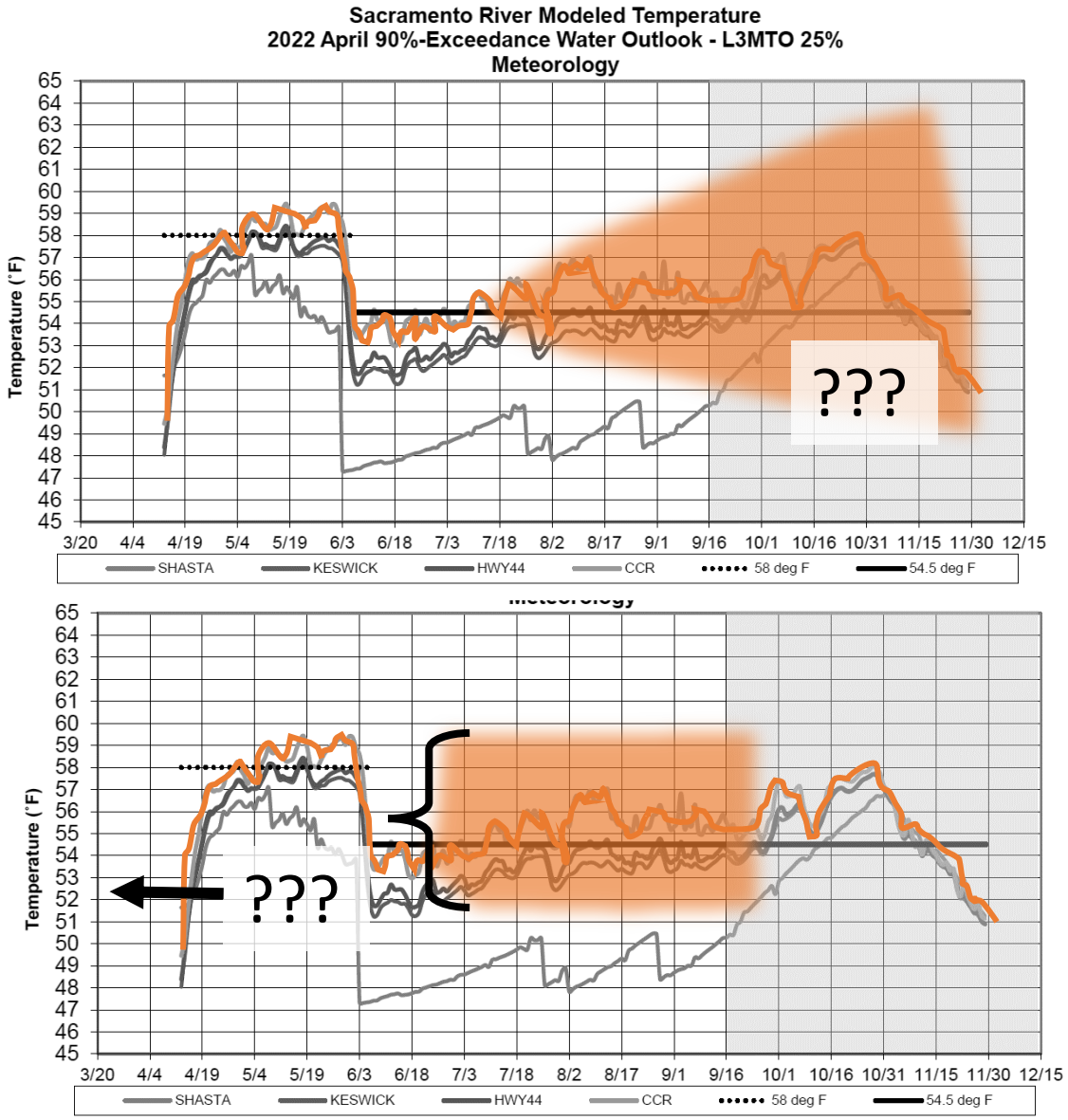
Background: Forecasting for WRC Management

- Temperature management plan projects how US Bureau of Reclamation operation of Shasta will affect water temperatures downstream



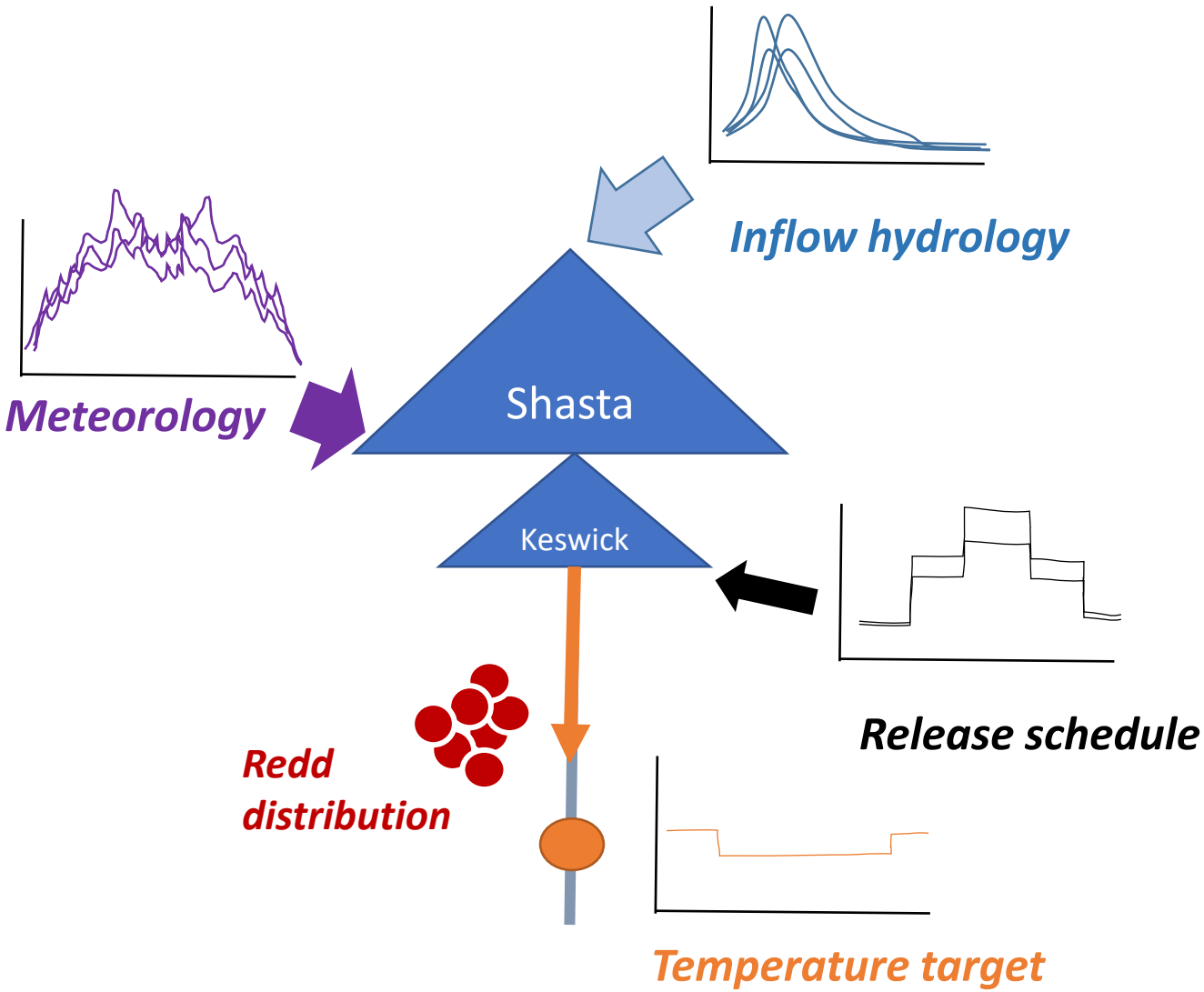
Background: Forecasting for WRC Management

- Tradeoffs between storage, cold water, and summer releases
- Decision-making timeline: Allocations occur before temperature conditions are "certain"
- Leads to questions like:
  - "How uncertain are any given temperature or TDM forecasts?"
  - "How early can we make confident predictions about temperature/TDM?"



Water temperature forecasts need input forecasts…

- Each input forecast is uncertain
- How much do these uncertainties matter?



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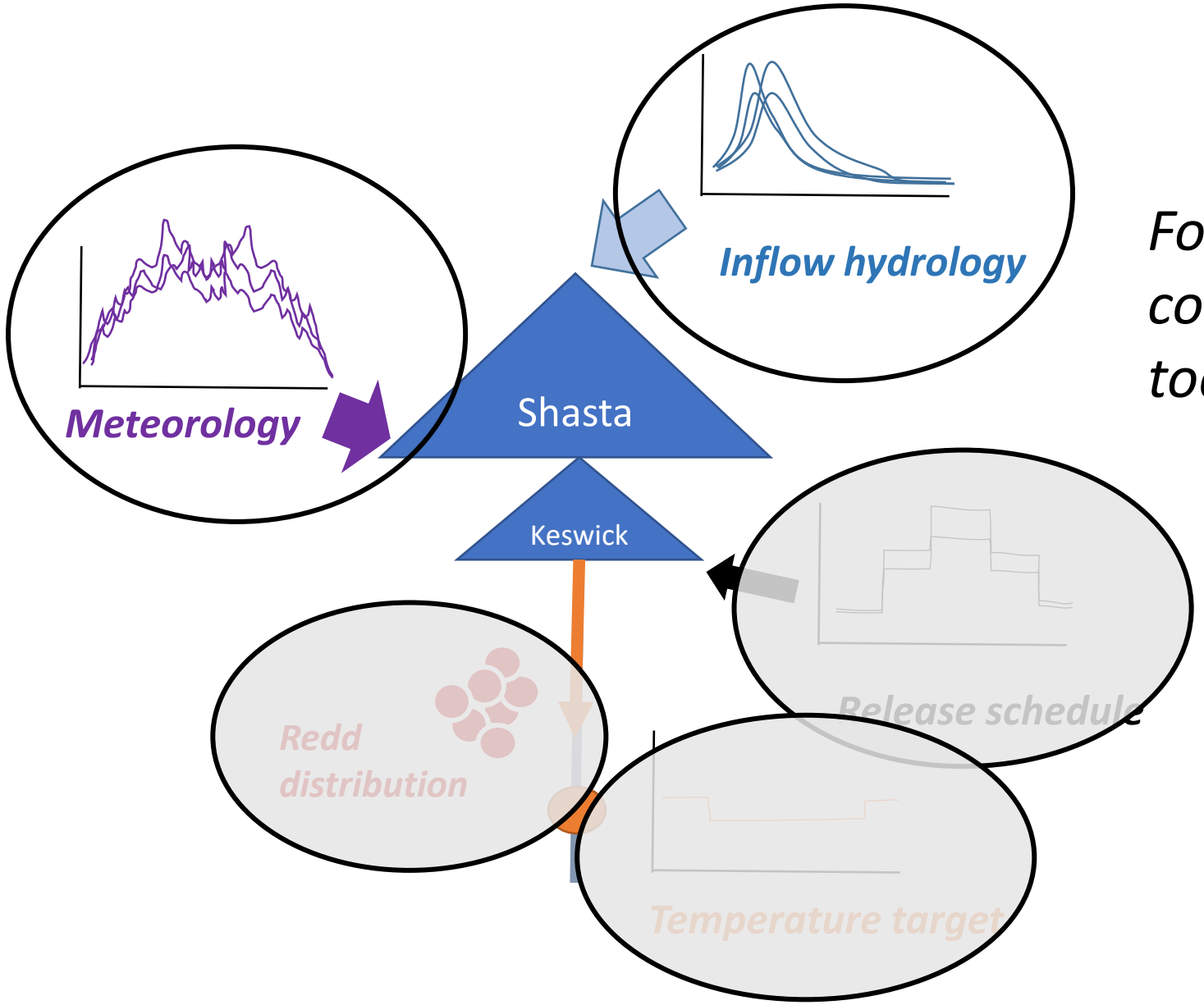
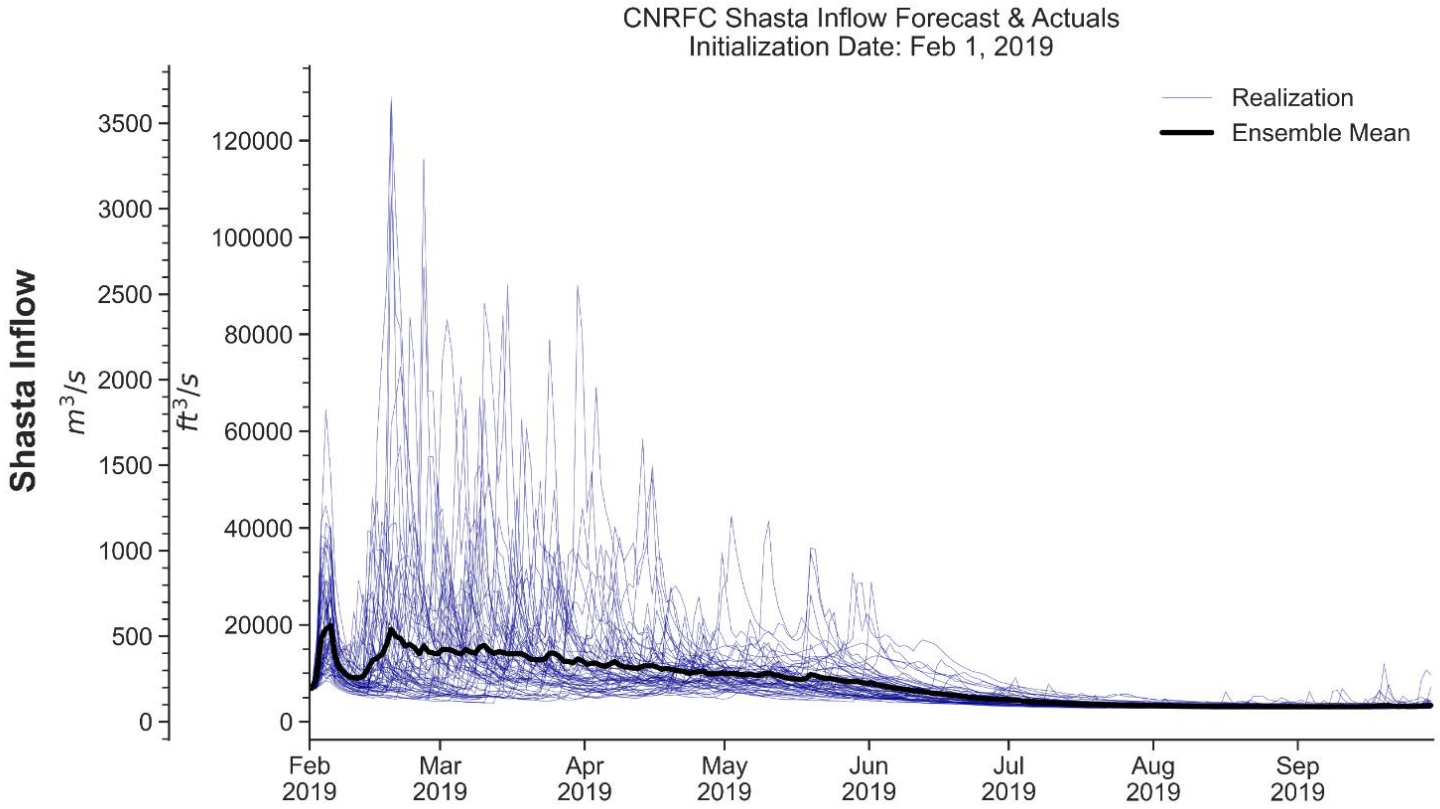


Focusing on two components today

Hydrologic uncertainty – Seasonal runoff forecasts

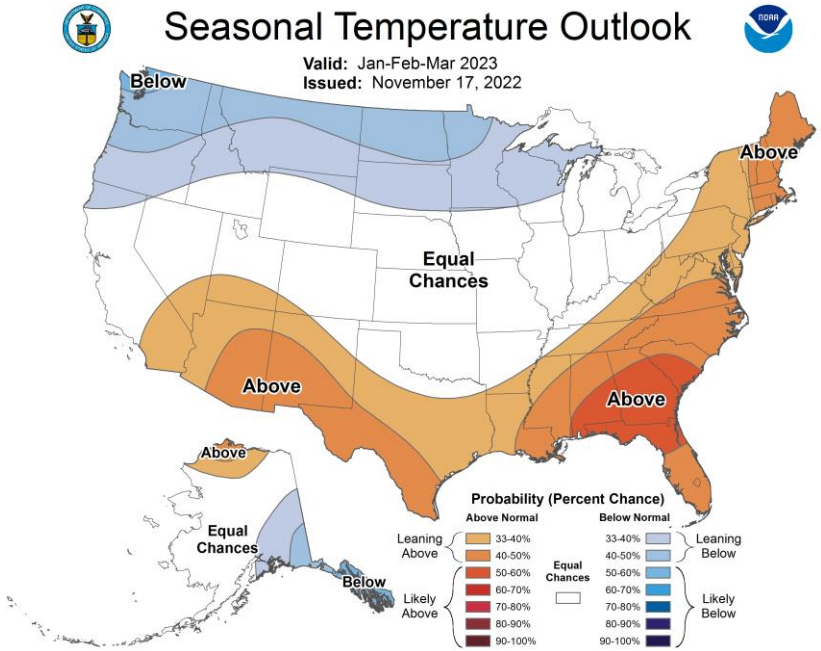
Inflow hydrology

- ***Ensemble streamflow forecasts via California-Nevada River Forecast Center***
- Hydrologic models driven by forecast meteorology (days 1-28) and 41-member climatology (days 29-365)

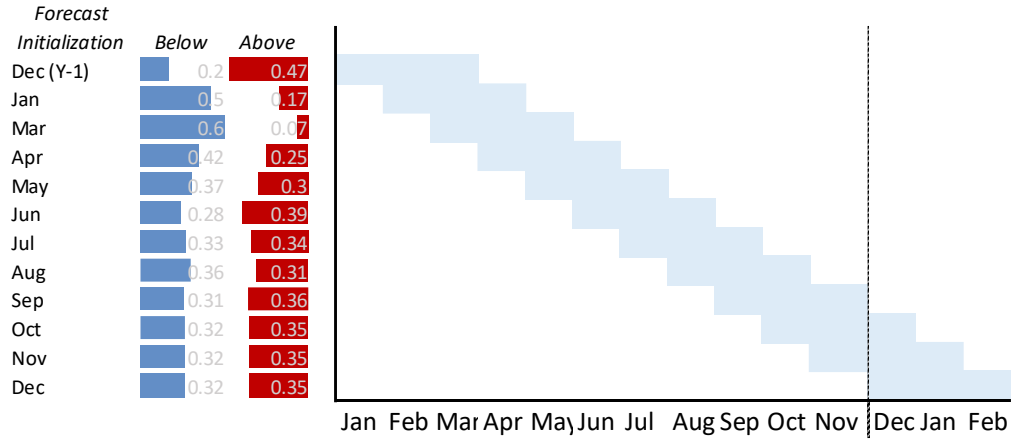


Meteorological Uncertainty – Air Temperature

- ***NOAA Climate Prediction Center seasonal projections***
- Probabilities for conditioning meteorological realization resampling



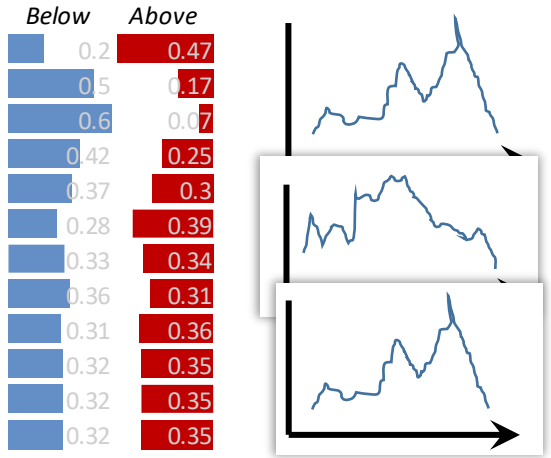
Overlapping 3-month temperature and precipitation probabilities for above, normal, and below-normal categories



Meteorological Uncertainty – Air Temperature

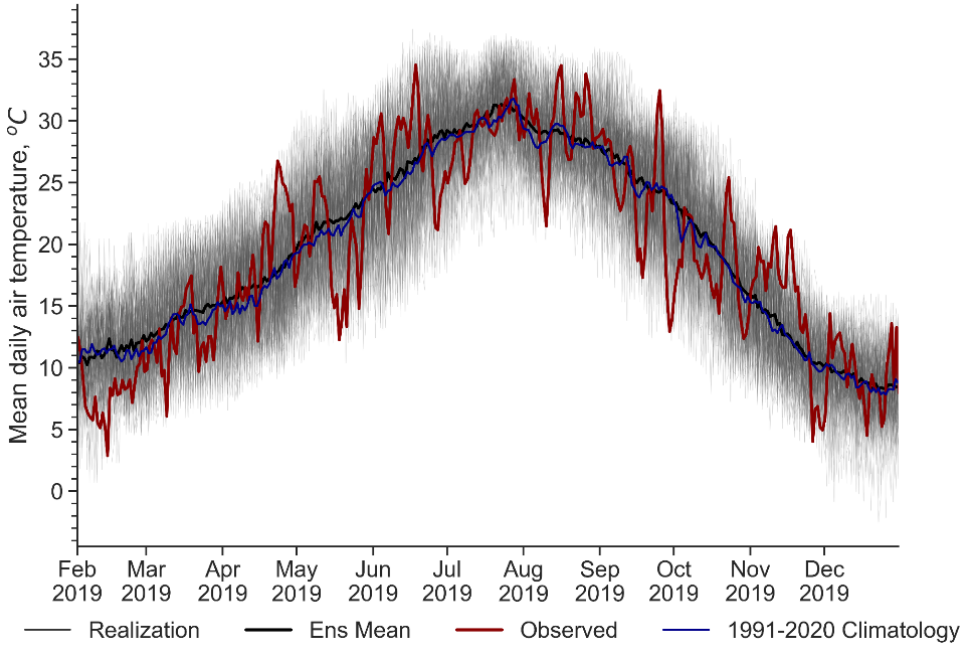
NOAA Climate Prediction Center seasonal projections

- "Schaake shuffle" using CPC projections to condition resampling from historical multivariate meteorological data
- Used GridMet grid cell collocated with climate normal station for complete/continuous multivariate record



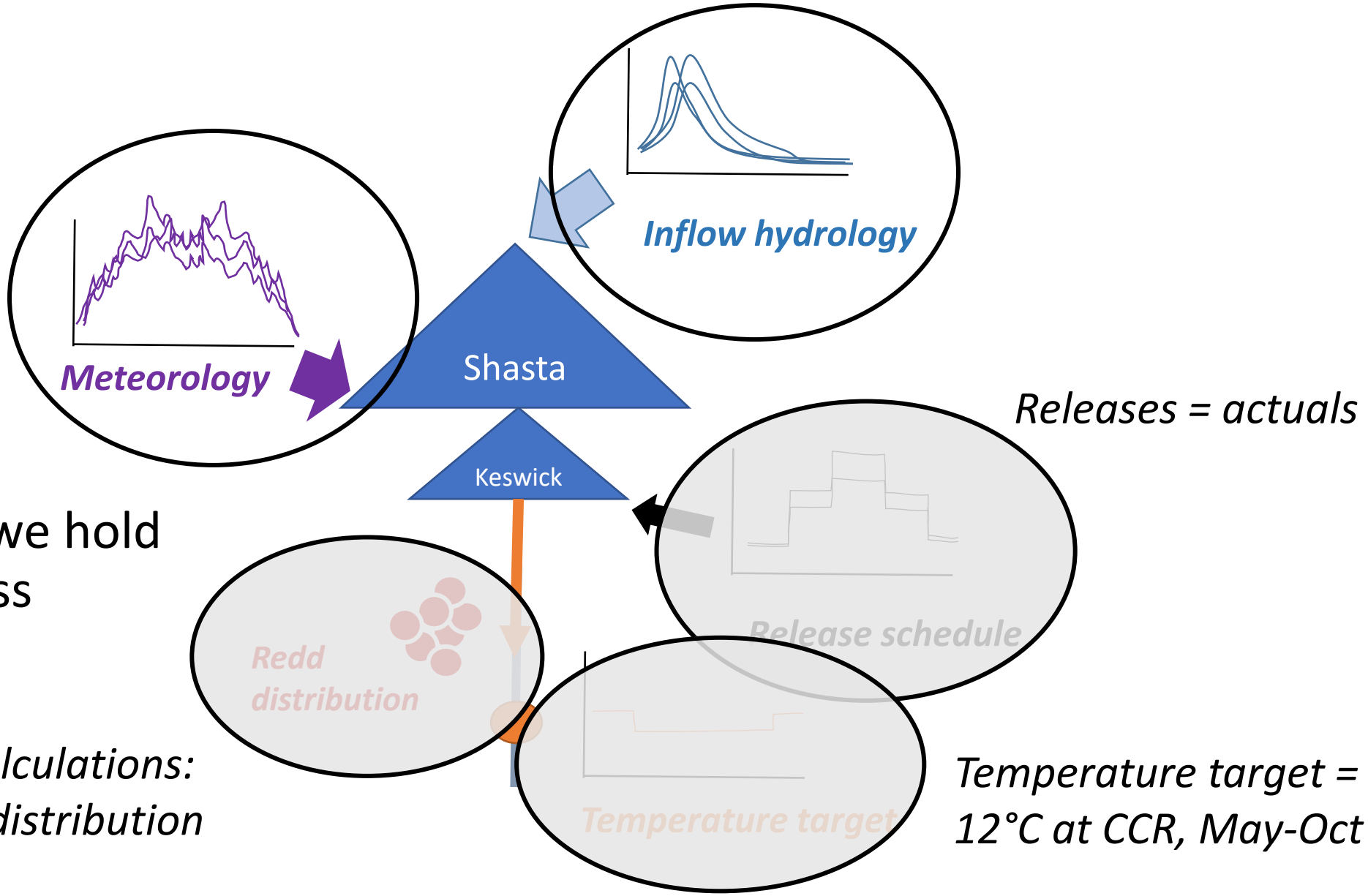
Forecast terciles

Conditional resampling historic data



Shuffle and combine

Water temperature forecasts need input forecasts…



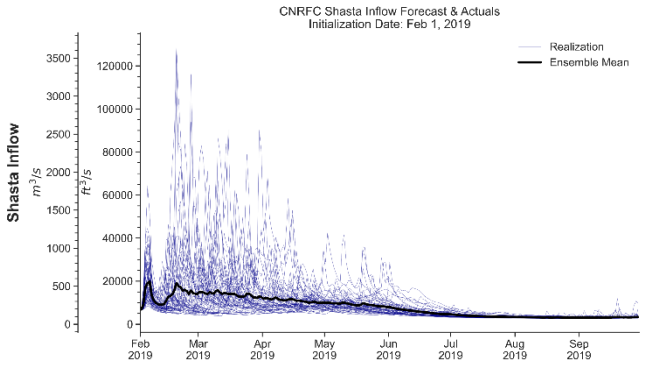
- Components we hold constant across simulations:

For TDM calculations: 2021 redd distribution

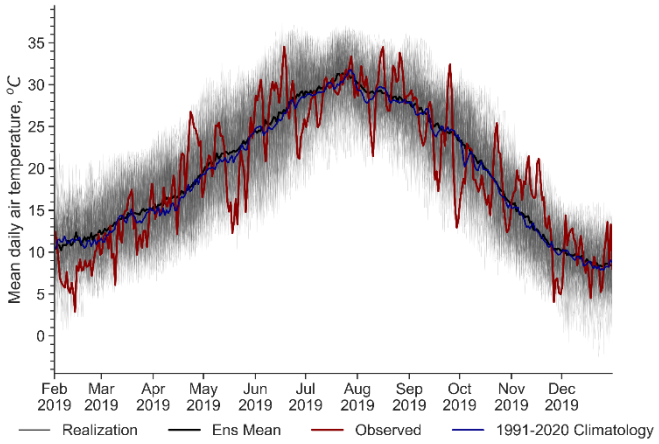
A Modeling Framework for Ensemble Managed Water Temperature Projections

Forecast initialization dates each year:

Feb 1
Mar 1
Apr 1
May 1
Jun 1

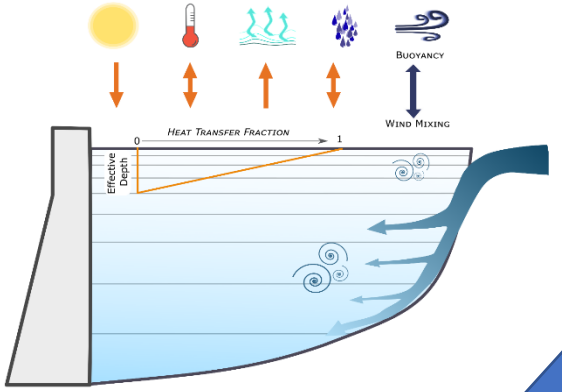


~40 ensemble members

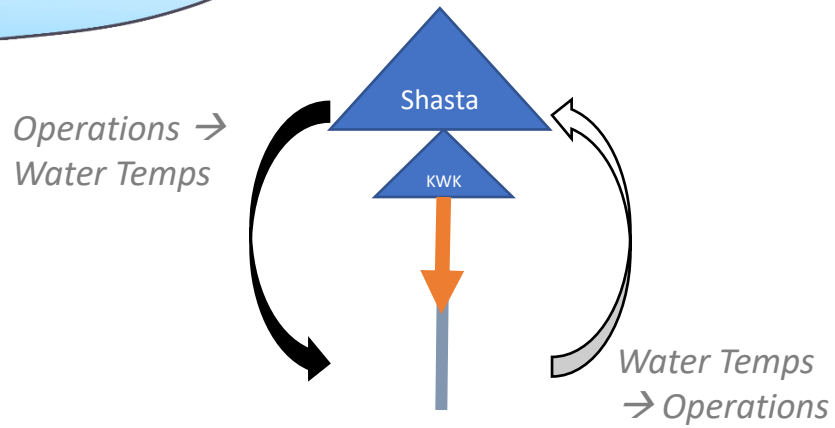


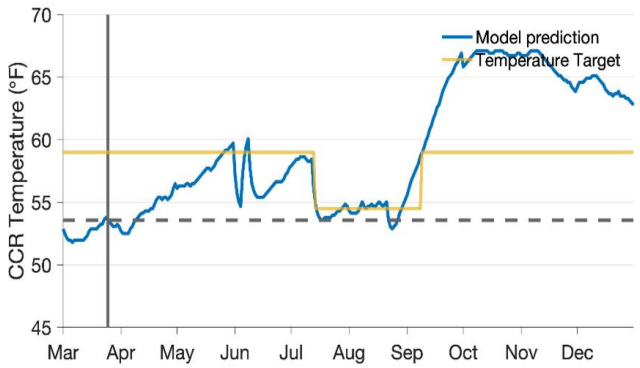
~50 ensemble members

~2000 hydromet combinations
X
5 initialization
=
~10,000 simulations



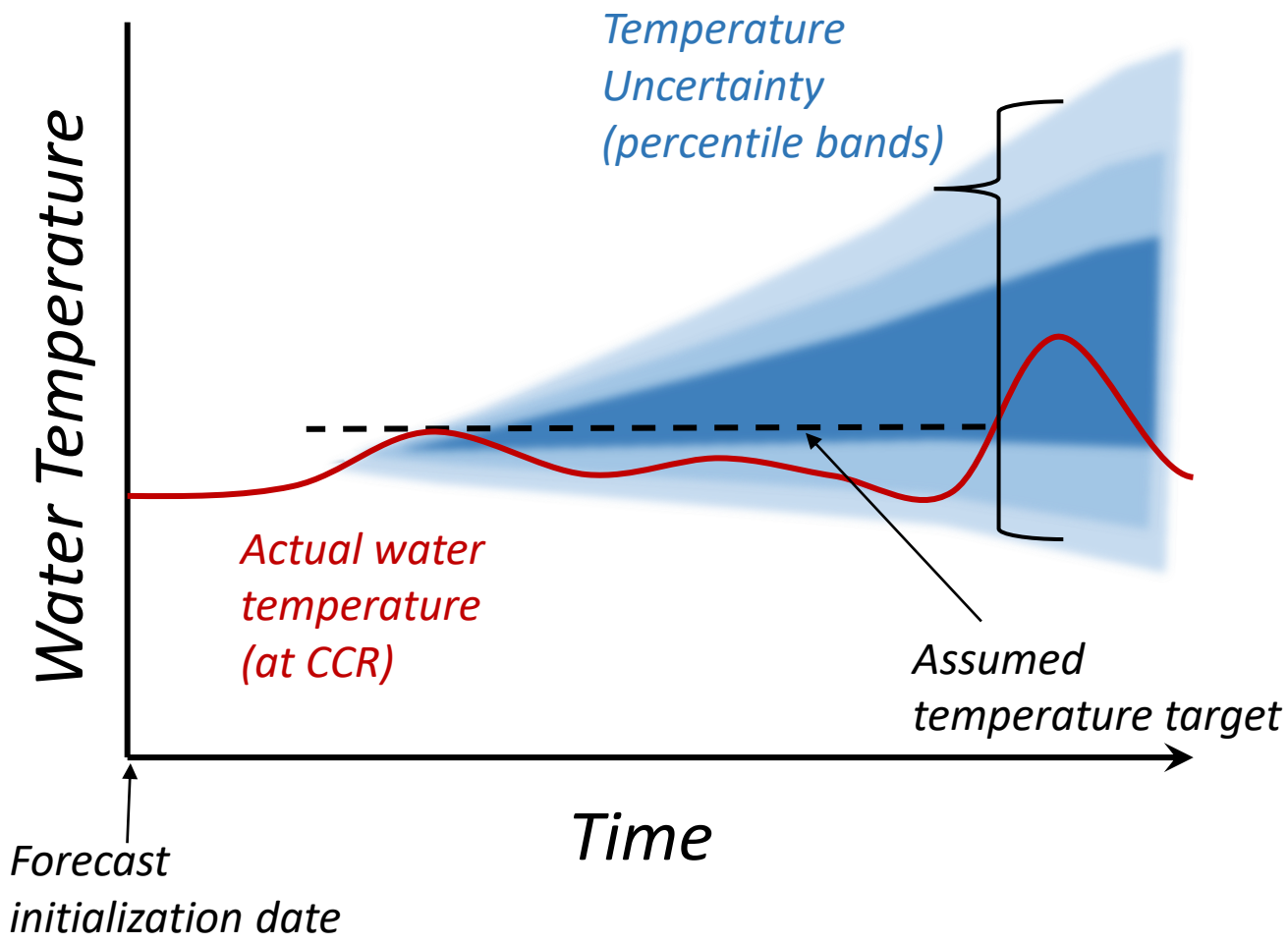
Rapid Assessment Temperature Modeling Framework





Results: How uncertain are water temperature projections at different lead times?

- Forecast lead times – Sept 1 water temperature
  - Feb 1 → 7 months
  - Mar 1 → 6 months
  - Apr 1 → 5 months
  - May 1 → 4 months
  - Jun 1 → 3 months
- CCR compliance point for evaluation
- Ensemble spread measure of uncertainty in water temperatures



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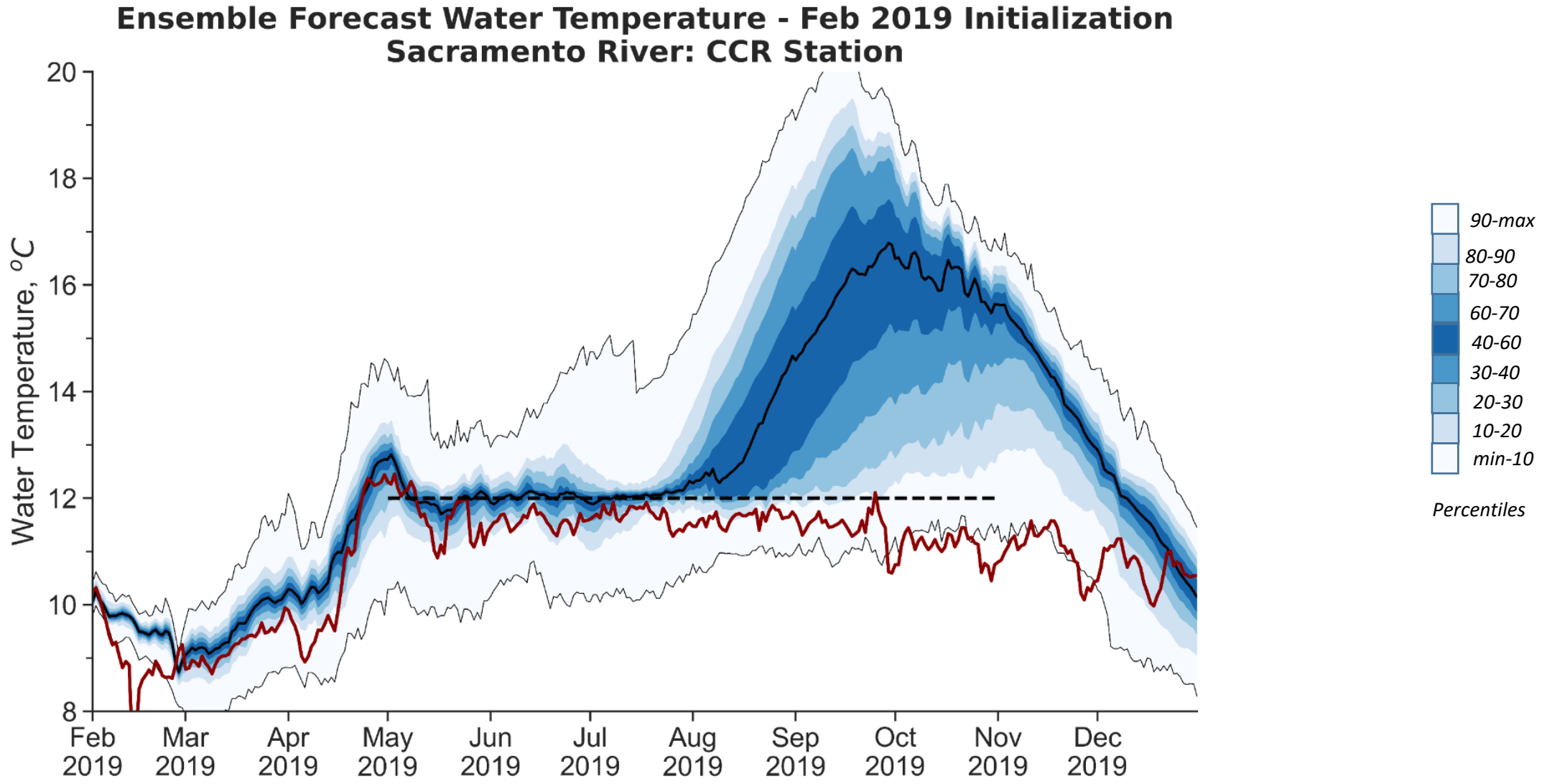

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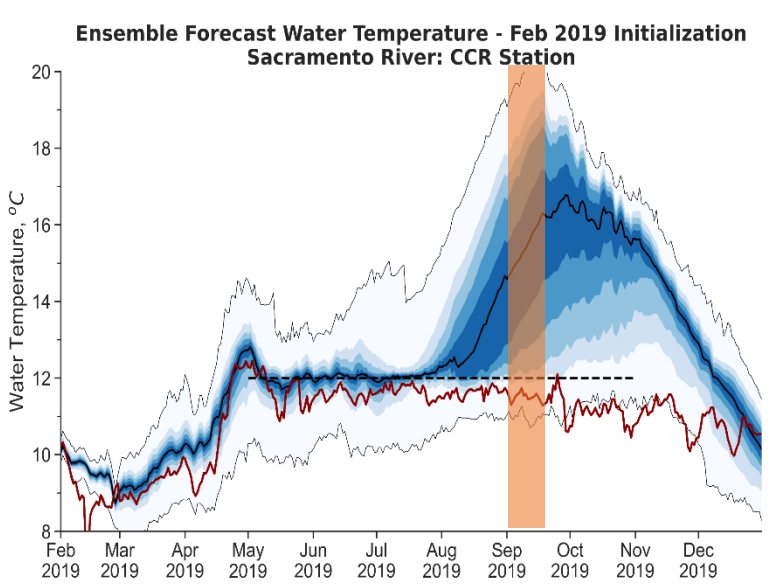
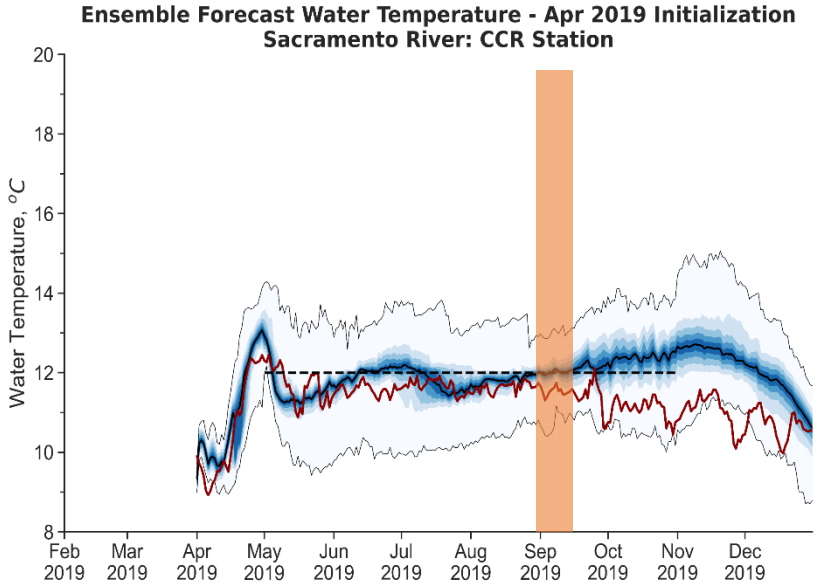
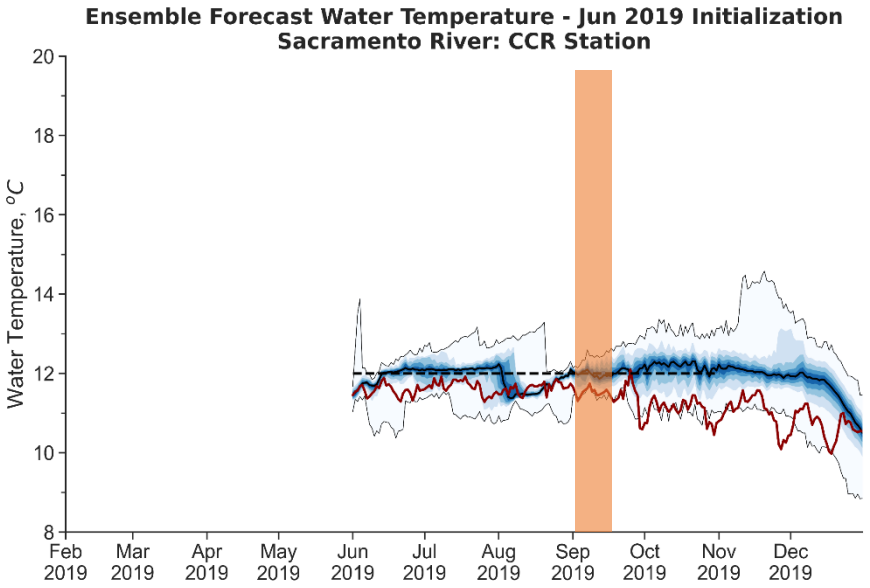






Feb 1 → 7 months

High uncertainty in September temperatures

Apr 1 → 5 months

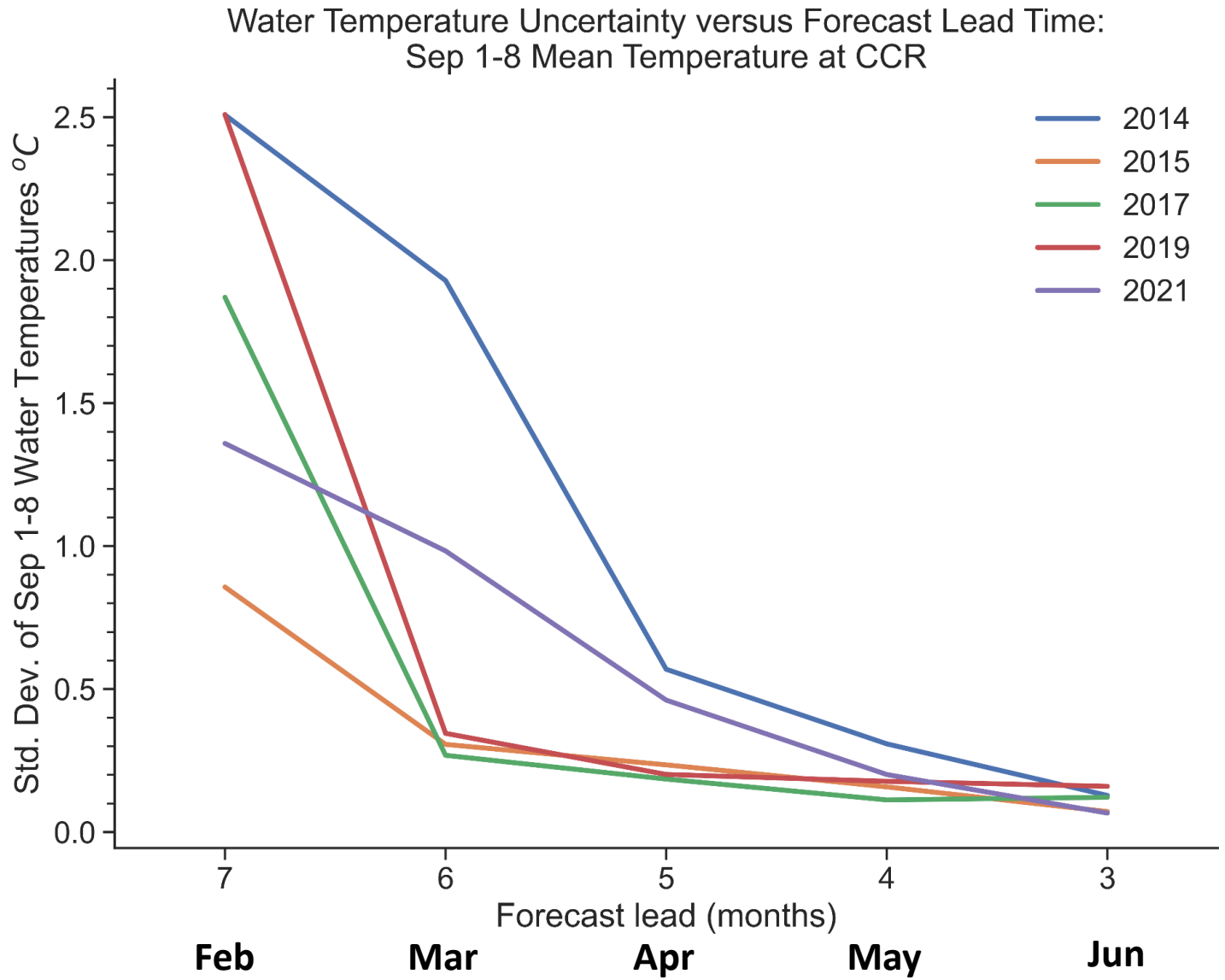
Uncertainty substantially reduced

Jun 1 → 3 months

Lowest September temperature uncertainty

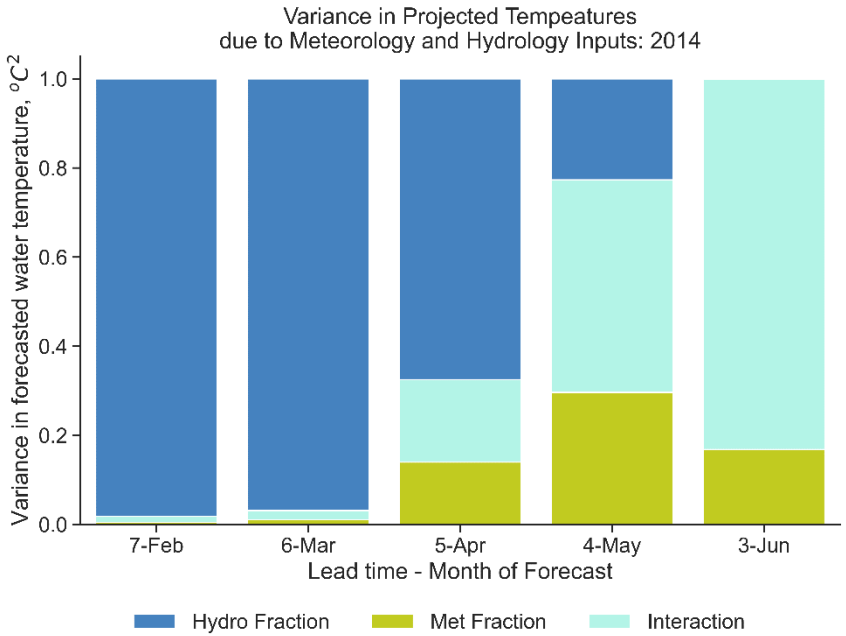
Example: Evaluate uncertainty for a period of interest: Sept 1-8

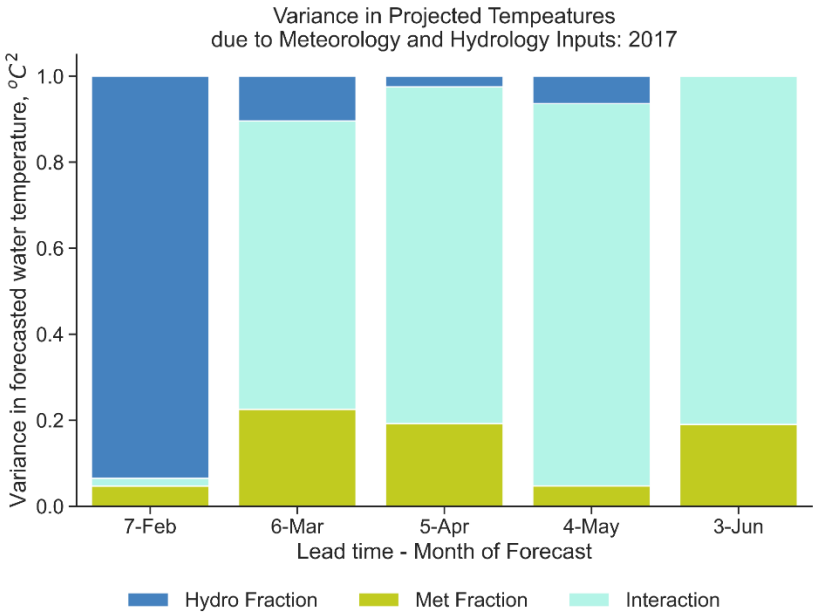
Results: How uncertain are water temperature projections at different lead times?

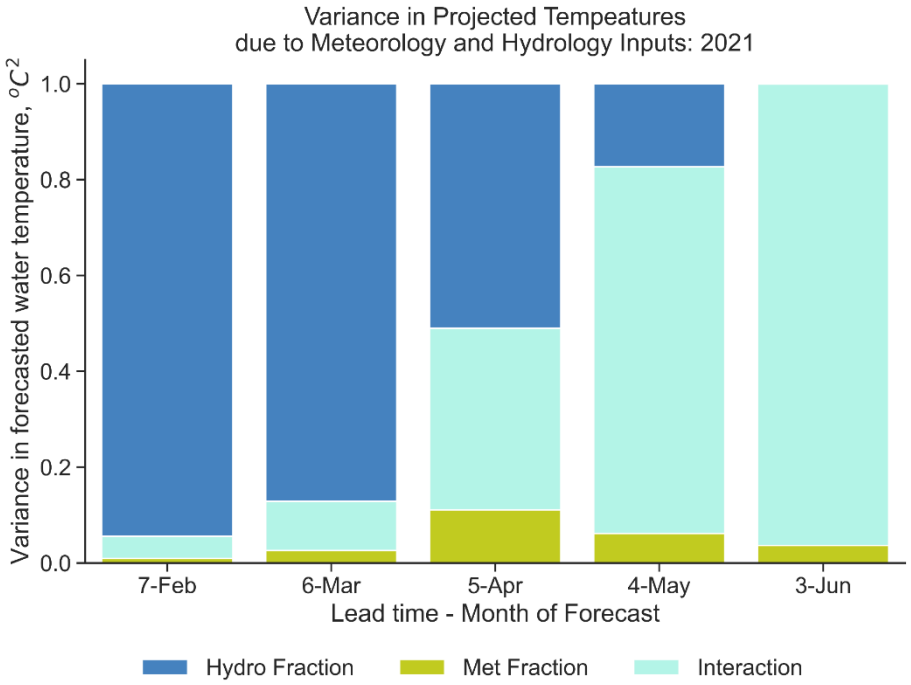


- *February (7-month leads) least predictability*
- *Uncertainty drops quickly in 2019,2017, and 2015*
- *Lower early uncertainty in 2015? An effect of storage and release schedules on mitigating hydro forecast uncertainty on temperature forecast?*

Results: How do meteorology and hydrology input uncertainties contribute to water temperature uncertainties?







All years: hydrologic forecast uncertainty dominates in February

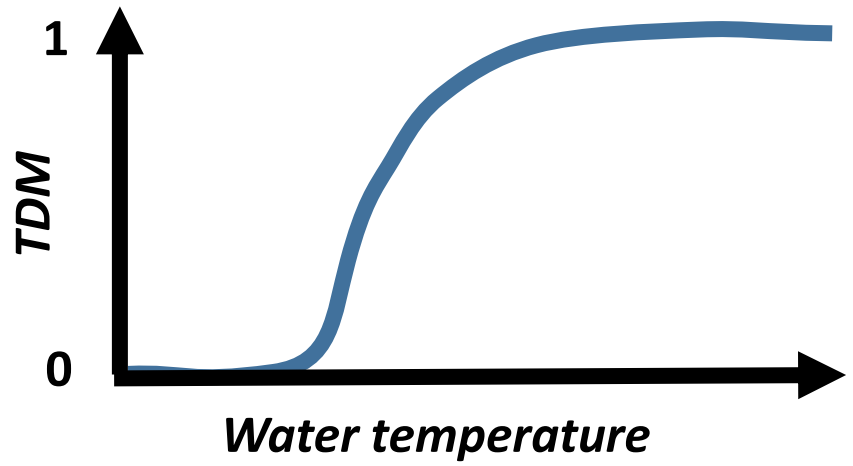
Two drought years (left): Hydrologic uncertainty dominates through April

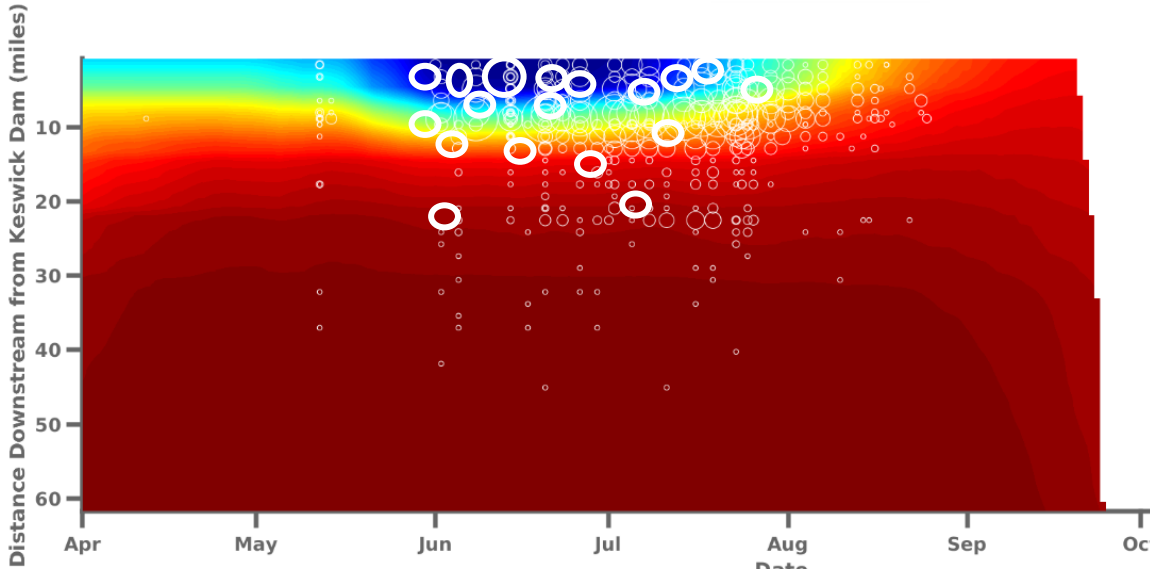
High storage year (top right): Interaction between meteorological and hydrologic uncertainty dominates early

How does uncertainty propagate to TDM?

Temperature dependent mortality (TDM) integrates the effect of water temperature over spawning season

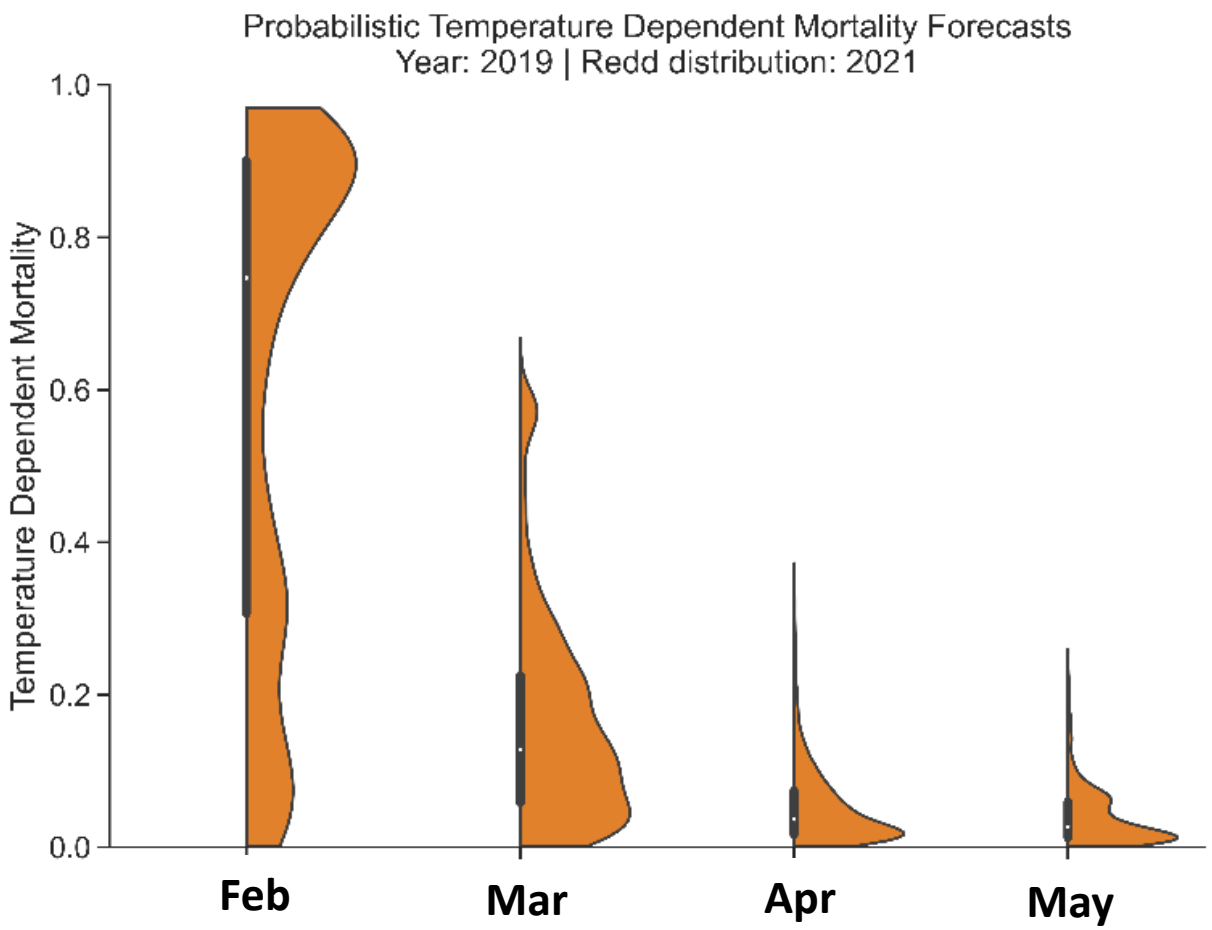
- *Egg survival depends on temperature history*
- *TDM calculated for each egg nest (redd) in the river*
- *Aggregate measure: mean for all redds*
- *Timing and location of redds varies each year – assuming 2021 for this analysis*





Source: https://oceanview.pfeg.noaa.gov/CVTEMP/river/survival

How does uncertainty propagate to TDM?
Two examples – two extremes



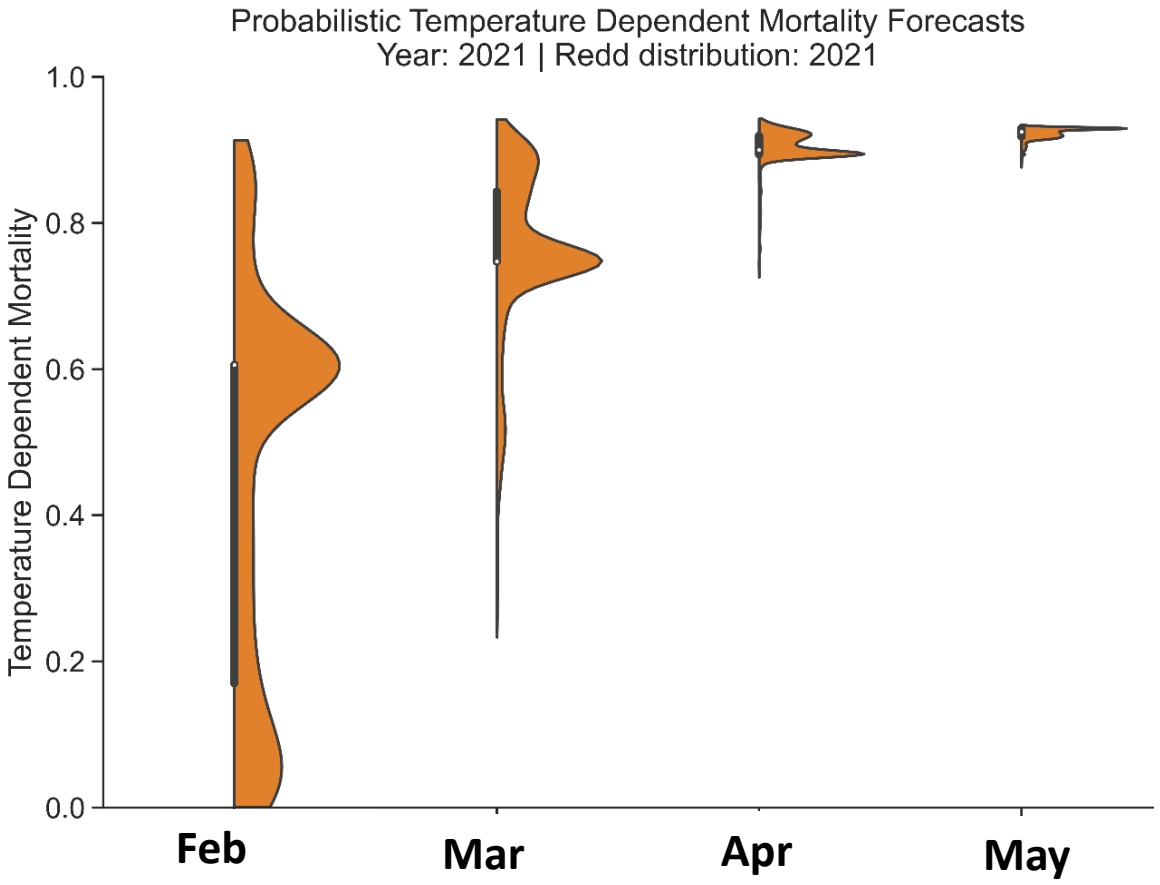
First example - 2019:

- February forecast very uncertain, but weighted towards high TDM
- Subsequent months converge towards more certain, lower TDM values
- *Reason:* runoff forecasts were biased too dry in February

How does uncertainty propagate to TDM?
Two examples – two extremes

Second example - 2021:

- February forecast again very uncertain
- Subsequent months converge towards more certain, higher TDM values
- *Reason:* Feb and Mar runoff forecasts were too wet



Summary & Next Steps

- Combination of ensemble streamflow and meteorological forecasts provide useful foundation for probabilistic temperature management projections
- For the Shasta-Sacramento system:
  - February (7-month lead) forecasts are most uncertain/least predictable
  - Runoff forecast uncertainty drives early season water temperature forecast uncertainty
  - Progression of uncertainty reduction not the same across all years
  - Temperature uncertainty can be translated to a probabilistic TDM projection – with similar qualitative evolution in uncertainty

Summary & Next Steps

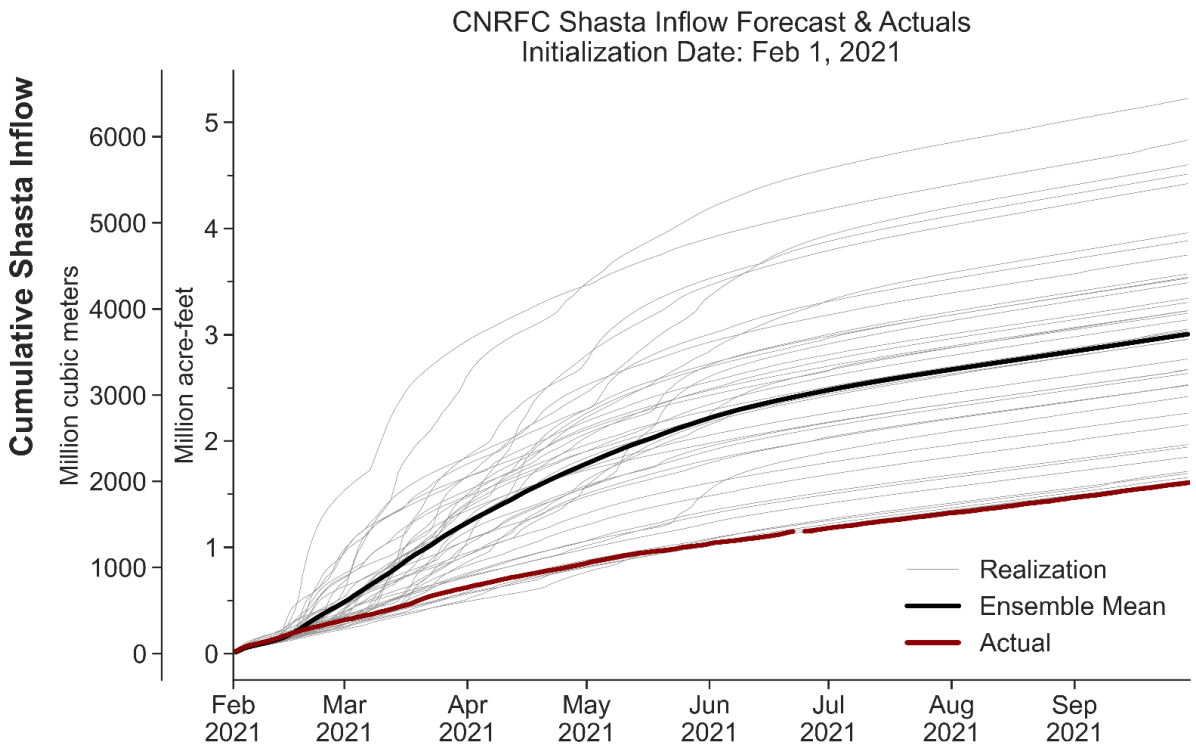
- This analysis examines *one* characterization of input uncertainty – room for refinement
- Model framework provides mechanism for improving understanding of improved runoff forecasts value to temperature management
- Results so far suggest reservoir storage, release timing/volume, and temperature target strategies all may affect uncertainties in forecast
  - *Are there operational approaches that lend themselves to more certain predictions of water temperature/TDM?*
- Biological uncertainty may be important too
  - *Incorporate stochastic models of WRC spawning timing and location*

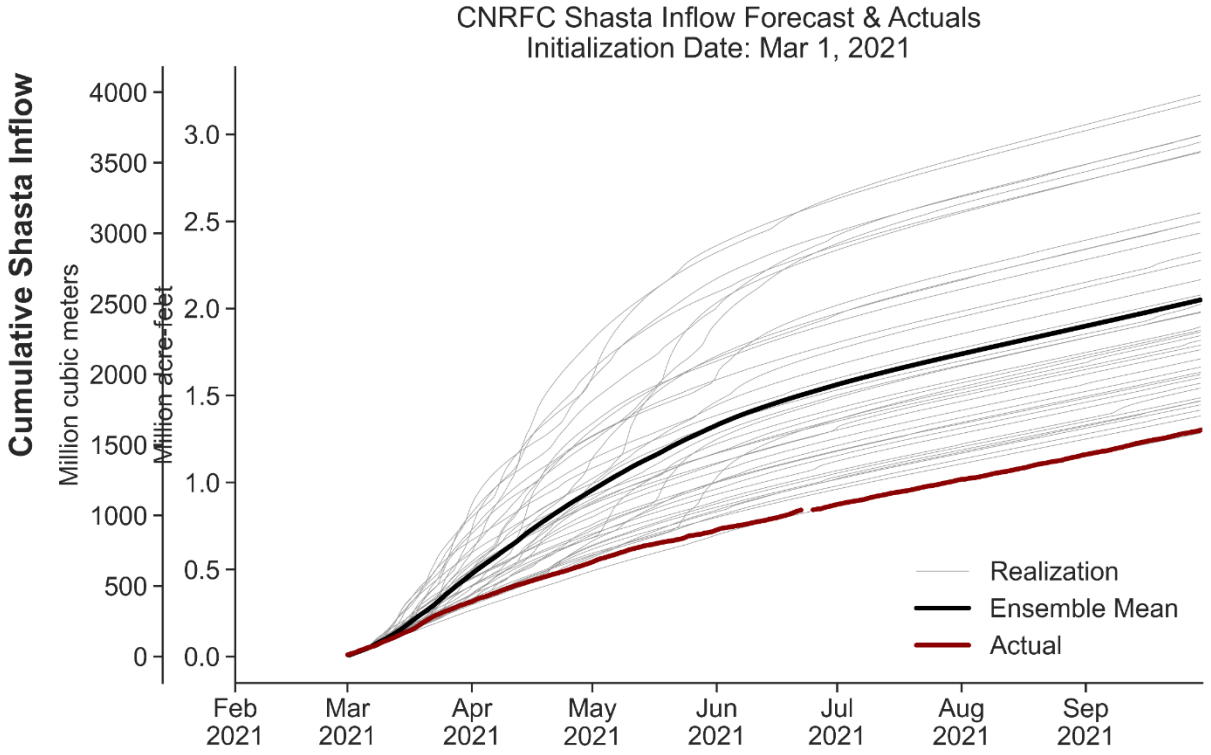
Photo credit: USBR

Photo credit: NOAA Fisheries

Questions?

Runoff Forecast Bias: 2021





Runoff Forecast Bias: 2019