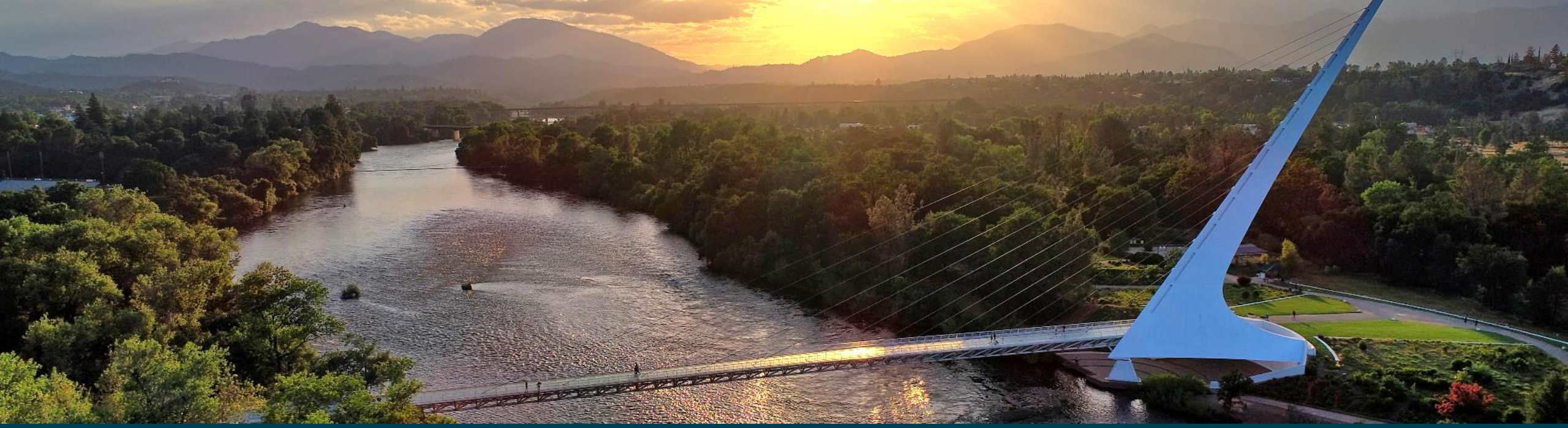


Photo credit: John Hannon, Reclamation

The Games We Play

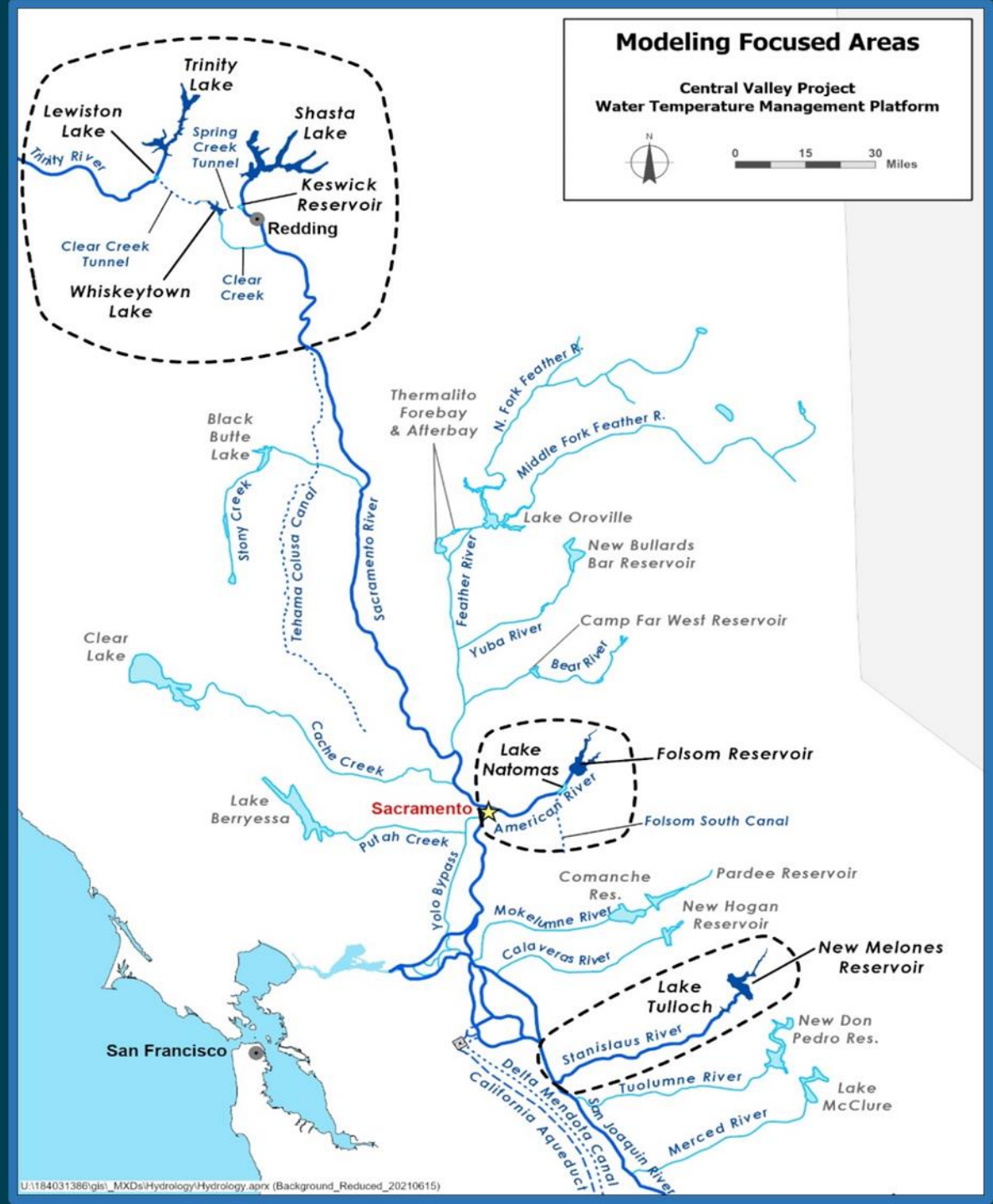
-Highlights of Model Calibration and Validation

Mike Deas, PhD, PE, Watercourse Engineering, Inc.

Craig Addley, PhD, PE, Stantec Consulting Services Inc.

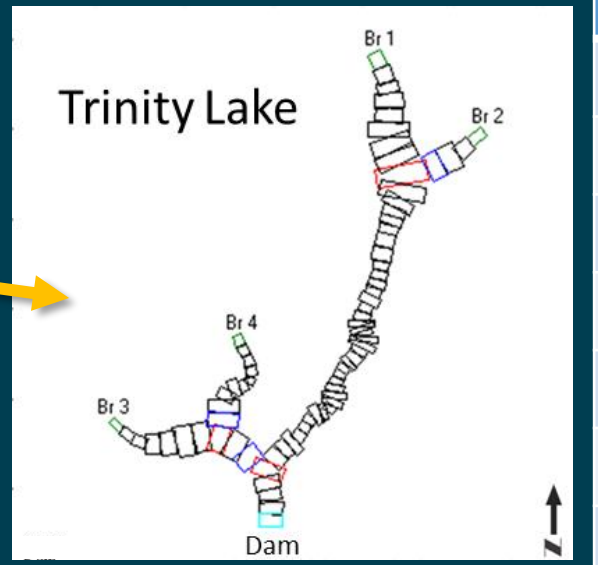
Modeling

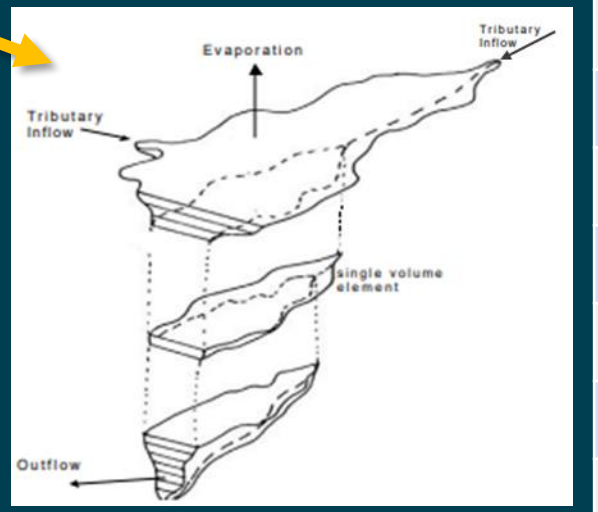
- Reservoir-river systems
  - 9 reservoirs
  - >200 miles of river
- Planning periods and simulation time-step
  - Sub-daily time-step
  - 2000-2021 period (available data)
- Information and data availability
  - Geometry (including unique attributes)
  - Hydrology and operations
  - Water temperature
  - Meteorology



Modeling

- CE-QUAL-W2
  - 2-dimensional
  - Laterally average
- HEC-ResSim
  - 1-dimensional
  - Reservoir
    - Laterally and Longitudinal average
  - River
    - Laterally and depth average

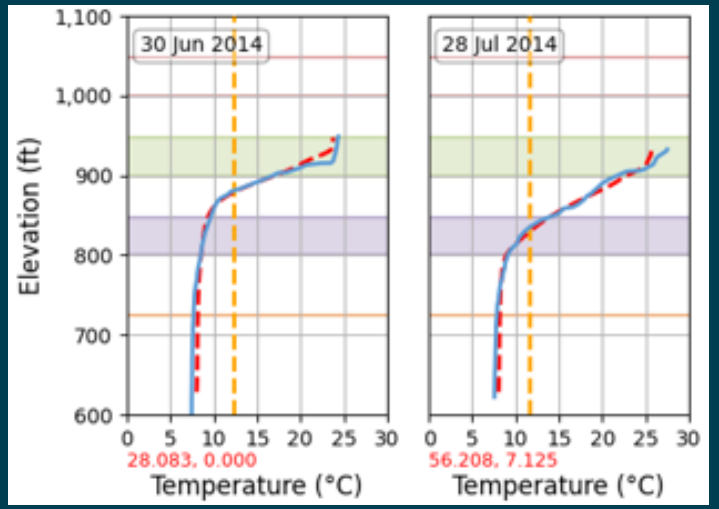




System/Element	CE-QUAL-W2	HEC-ResSim
Lake Shasta	●	●
Keswick Reservoir	●	●
Sacramento River	n/a	●
Whiskeytown Lake	●	●
Clear Creek	n/a	●
Trinity Lake	●	●
Lewiston Lake	●	●
Trinity River	n/a	●
Folsom Lake	●	●
Lake Natoma	●	●
American River	n/a	●
New Melones Lake	●	●
Tulloch Lake	●	●
Stanislaus River	n/a	●

Calibration Approach: Basics

- Graphical and statistical assessments
  - Stage
  - Reservoir vertical temperature profile
  - Reservoir outflow temperature
  - River water temperature (time series)



Statistic	Equation	Use
Mean Bias	$\text{Mean Bias, } \varepsilon = \frac{1}{n}\sum_{i=1}^{n}(Xsim_i - Xmeas_i)$	Systematic model over- or under-prediction
Mean Absolute Error	$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\lvert Xsim_i - Xmeas_i\rvert$	Estimate of overall model error
Root Mean-Squared Error	$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Xsim_i - Xmeas_i)^2}{n}}$	Large values indicate notable deviations (e.g., outliers)
Nash Sutcliffe Efficiency	$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(Xsim_i - Xmeas_i)^2}{\sum_{i=1}^{n}(Xmeas_i - \overline{Xmeas_i})^2}$	Indication of how well the plot of observed versus simulated data fits the 1:1 line

Calibration Approach: Metrics

- Model Performance Metrics

Parameter	Mean Bias	MAE	RMSE	NSE
Stage	±0.5 ft (0.15 m)	≤1.0 ft (0.3 m)	≤1.5 ft (0.45 m)	≥0.65
Flow	±150 cfs (4.2 cms)	≤300 cfs (8.4 cms)	≤500 cfs (14.2 cms)	≥0.65
Water Temperature	±1.3°F (0.75°C)	≤1.8°F (1.0°C)	≤2.7°F (1.5°C)	≥0.65

- Considerations for metric selections
  - Operating/management goals
  - Field measurement and monitoring
  - Model process representation (e.g., governing equations, parameterization)
  - Model system representations (e.g., geometric, spatial, temporal)
  - Regulatory targets/objectives
  - Model application experience

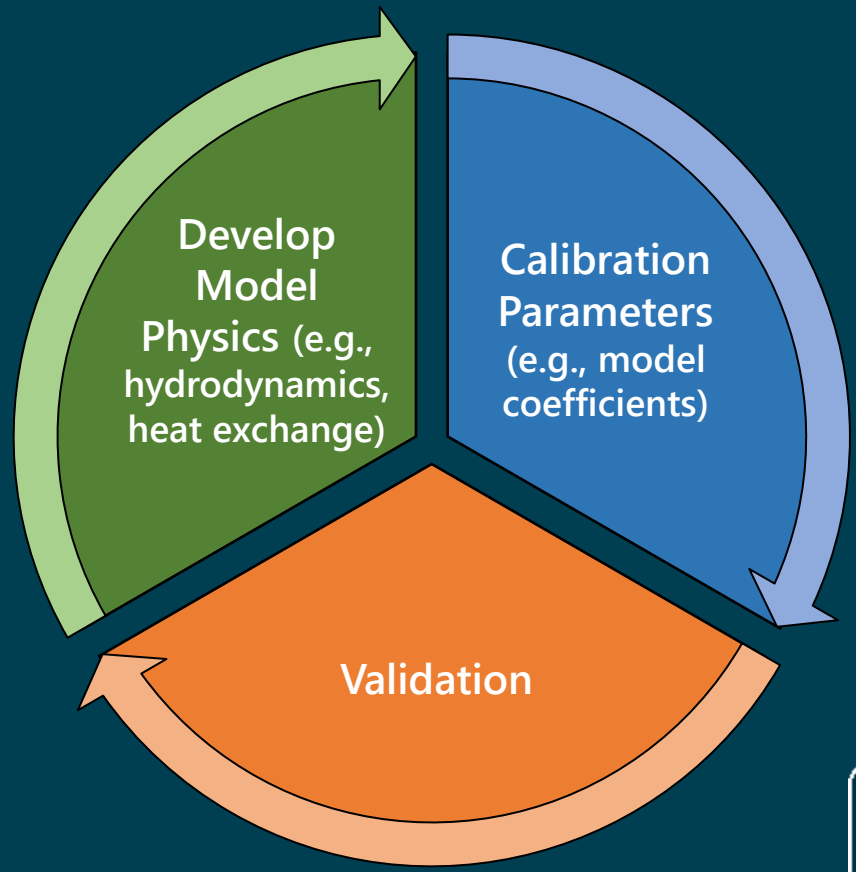
Calibration Approach: System Attributes We Focused on During Calibration

- Different systems require different performance assessment
- Range of hydrology, operations, meteorology, and temperature
- All years of available data

System	Focused Attributes	Calibration Approach	Examples
Large Reservoir	Long residence time, persistent seasonal stratification	Match thermal profile and outflow temperature	Shasta, Trinity, Folsom, New Melones
Medium Reservoir	Long residence time, upstream influence, persistent stratification	Match thermal profile and outflow temperature	Whiskeytown, Tulloch
Small Reservoir	Short residence time, upstream influence, intermittent stratification	Match outflow temperature (profile secondary)	Keswick, Lewiston, Natoma
River	Short residence time, upstream influence, meteorology response	Match diurnal range and mean daily temperature (longitudinal heating)	Sacramento, Trinity, American, Stanislaus

Model Verification: Calibration and Validation

- Remarkable calibration/validation data sets available on most systems
  - Real-time operations and flow/hydrology
  - Biological monitoring
  - Meteorology
- Once calibrated, model uncertainties are accepted as appropriate for application (e.g., forecasts)
- Forecast uncertainty
  - Boundary conditions (hydrology, meteorology, water temperature)
  - Operations



Summary of Model Calibration Results

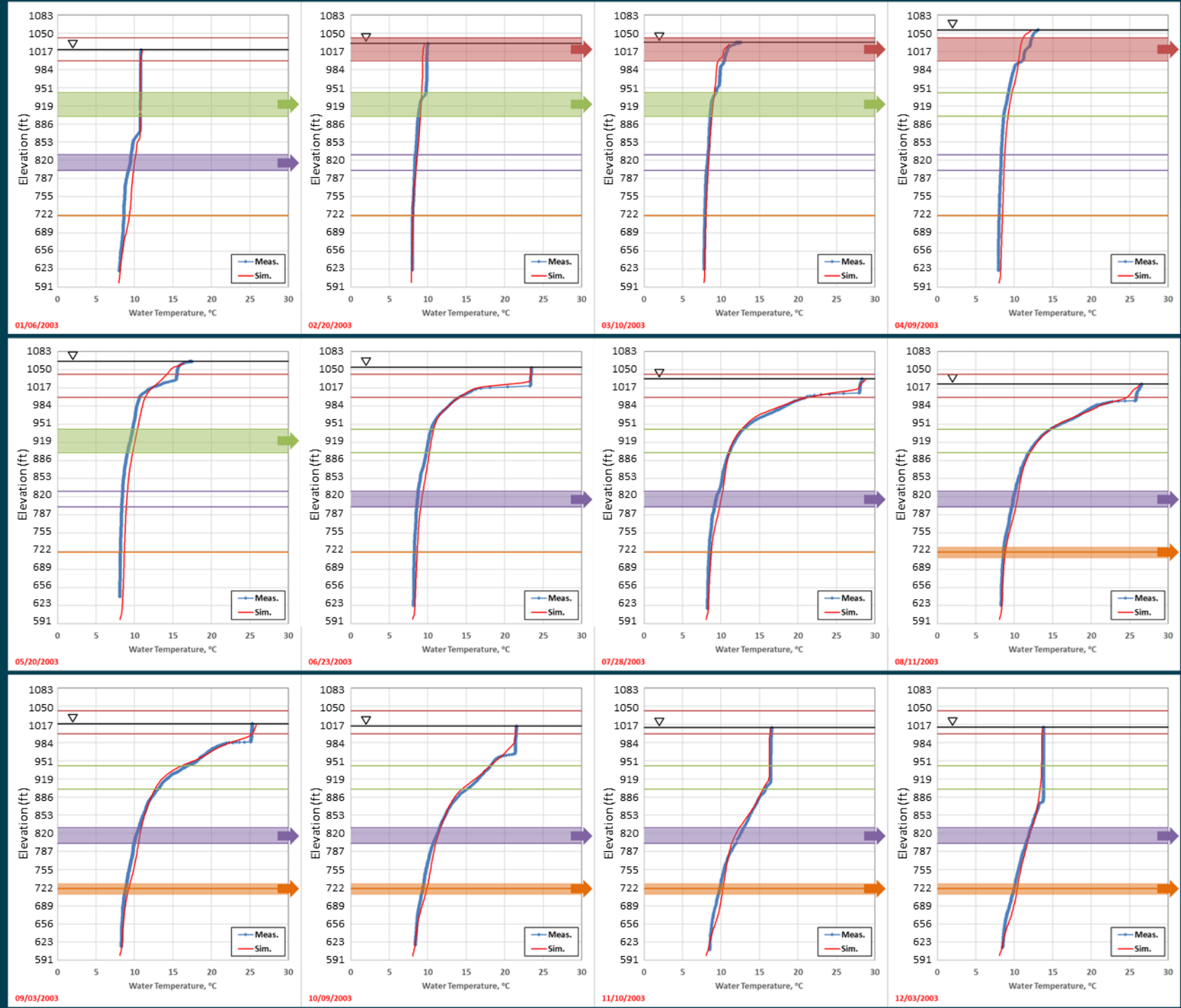
- Implemented models
  - CE-QUAL-W2
  - HEC-ResSim
- Effects of data limitations on model calibration results in the Stanislaus River system

System/Element	CE-QUAL-W2	HEC-ResSim
Lake Shasta	●	●
Keswick Reservoir	●	●
Sacramento River	n/a	●
Whiskeytown Lake	●	●
Clear Creek	n/a	●
Trinity Lake	●	●
Lewiston Lake	●	●
Trinity River	n/a	●
Folsom Lake	●	●
Lake Natoma	●	●
American River	n/a	●
New Melones Lake	◐	◐
Tulloch Lake	◐	◐
Stanislaus River	n/a	◐

LEGEND ● Good ● Fair ● Poor

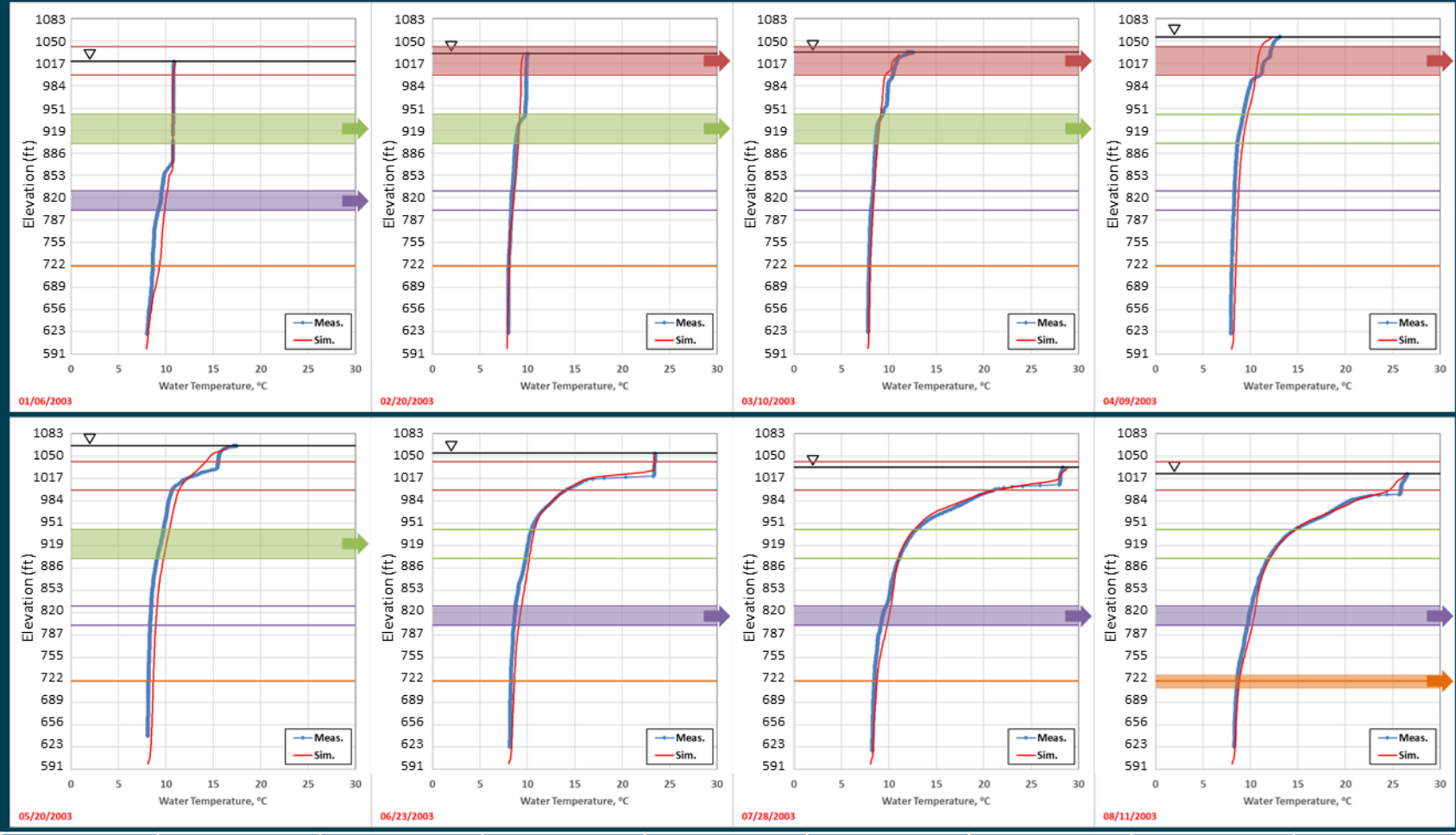
Sacramento River Basin - Shasta Lake

- CE-QUAL-W2
- 2003 Shasta Lake water temperature profile as an example



Sacramento River Basin - Shasta Lake

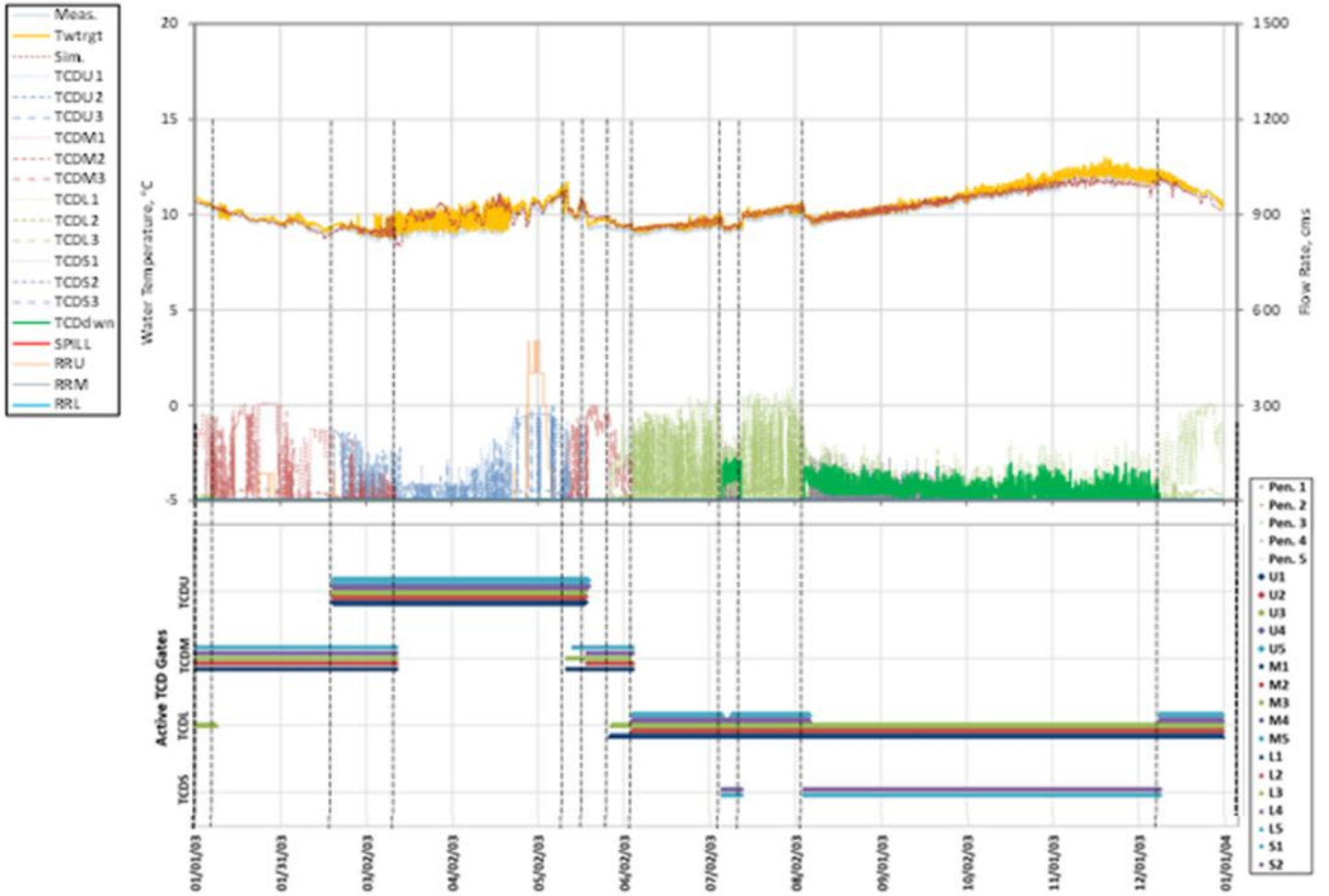
- CE-QUAL-W2
- 2003 Shasta Lake water temperature profile as an example



Statistic	01/06	02/20	03/10	04/09	05/20	06/23	07/28	08/11	09/03	10/09	11/10	12/03
Mean Bias (°C)	0.33	-0.04	0.02	0.27	0.43	0.25	0.11	0.16	0.12	0.07	-0.03	0.07
MAE (°C)	0.36	0.23	0.23	0.50	0.62	0.40	0.37	0.31	0.39	0.32	0.30	0.28
RMSE (°C)	0.48	0.30	0.28	0.53	0.66	0.59	0.51	0.40	0.48	0.40	0.35	0.33
NSE	0.79	0.82	0.91	0.83	0.90	0.98	0.99	0.99	0.99	0.99	0.99	0.97

Sacramento River Basin - Shasta Lake

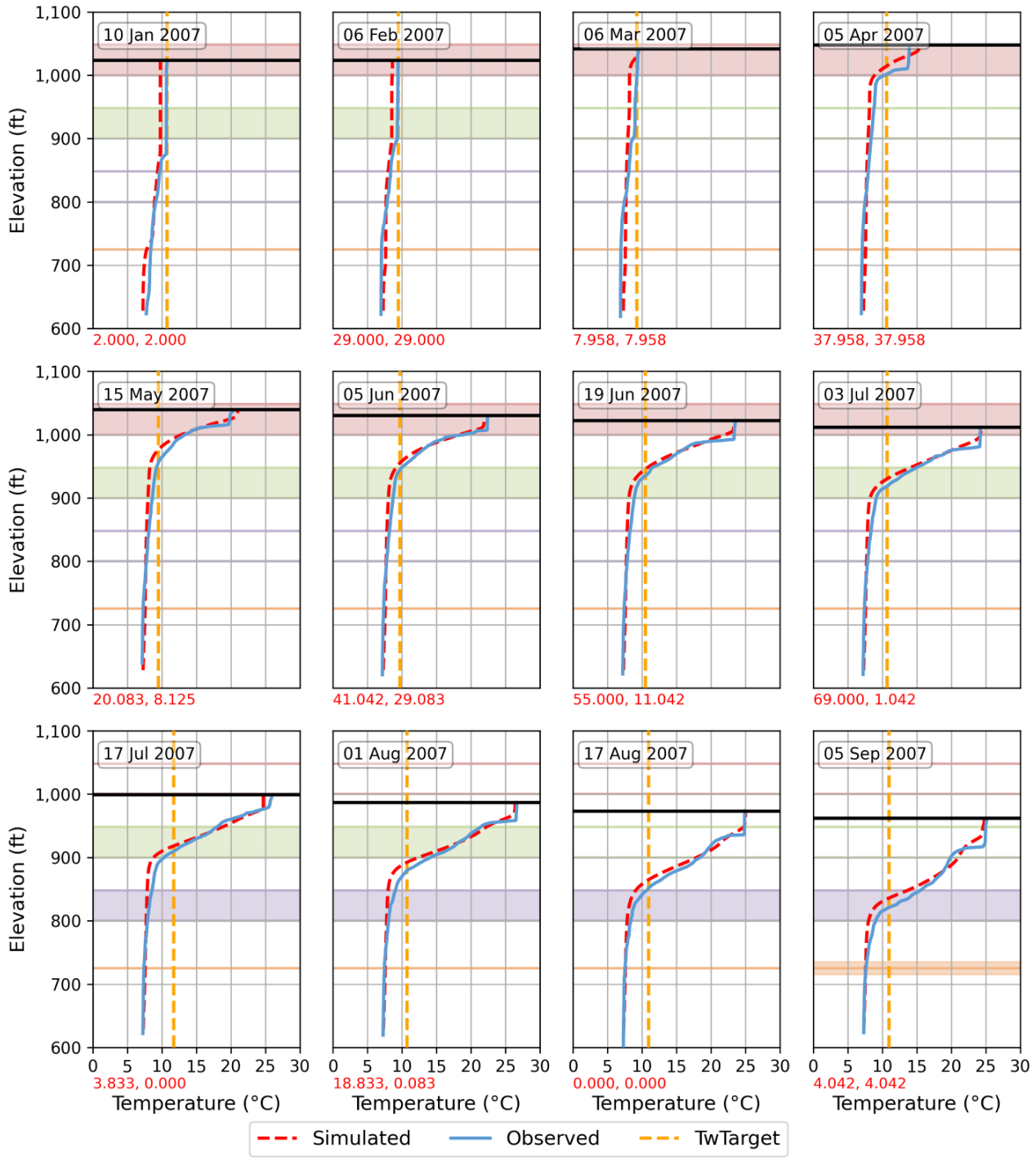
- CE-QUAL-W2
- 2003 reservoir outflow temperature as an example



Statistic	2000	2001	2002	2003	2004	2005	2006	2007	2008
Mean Bias (◦C)	-0.09	0.09	-0.01	**-0.11**	-0.42	-0.06	-0.31	-0.29	-0.25
MAE (◦C)	0.61	0.36	0.31	**0.20**	0.47	0.15	0.33	0.38	0.37
RMSE (◦C)	0.75	0.59	0.45	**0.31**	0.73	0.25	0.47	0.64	0.68
NSE	**0.53***	0.85	0.88	**0.88**	0.85	0.97	0.78	0.82	0.92

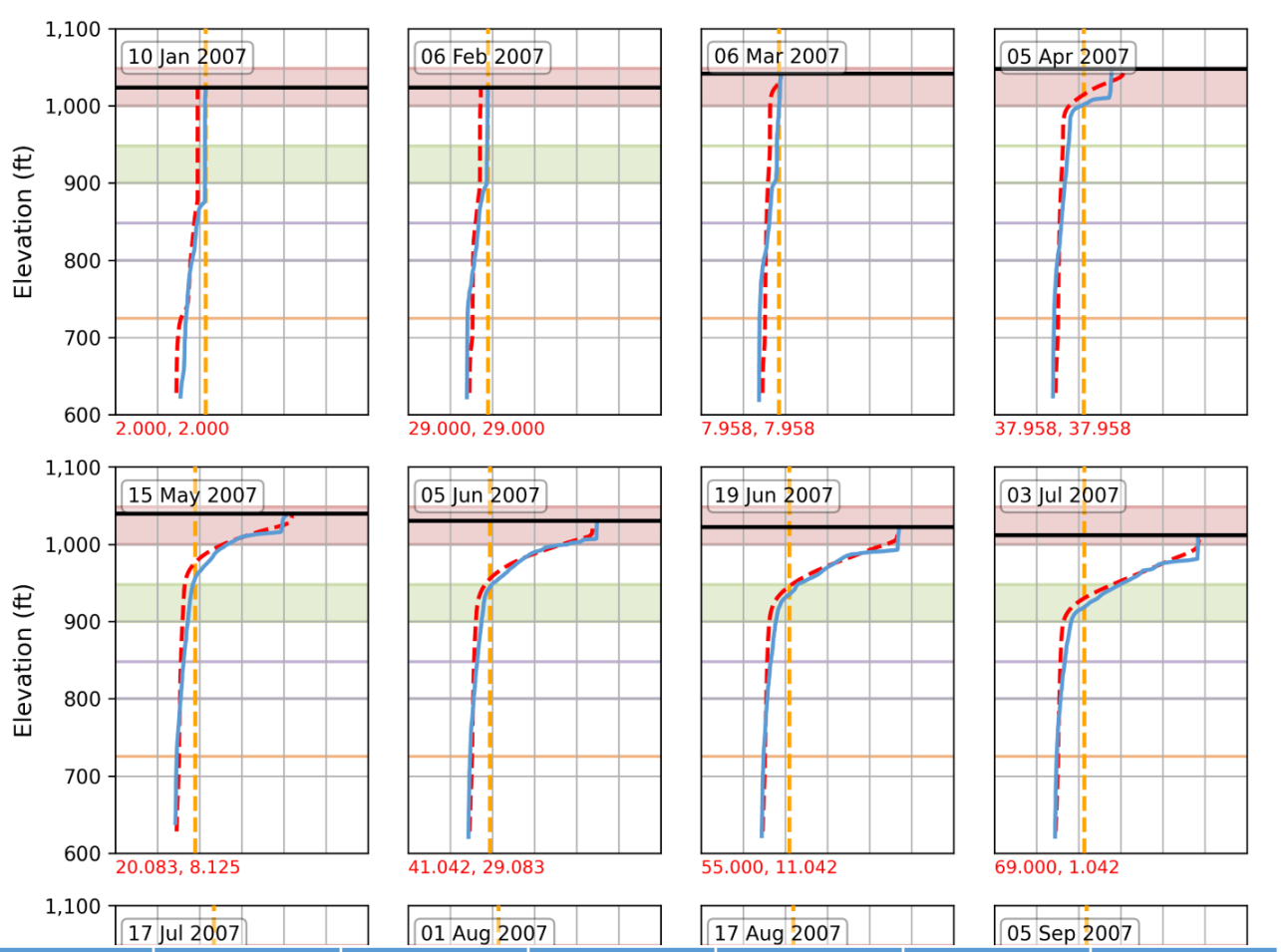
Sacramento River Basin - Shasta Lake

- HEC-ResSim
- 2007 Shasta Lake water temperature profile as an example



Sacramento River Basin - Shasta Lake

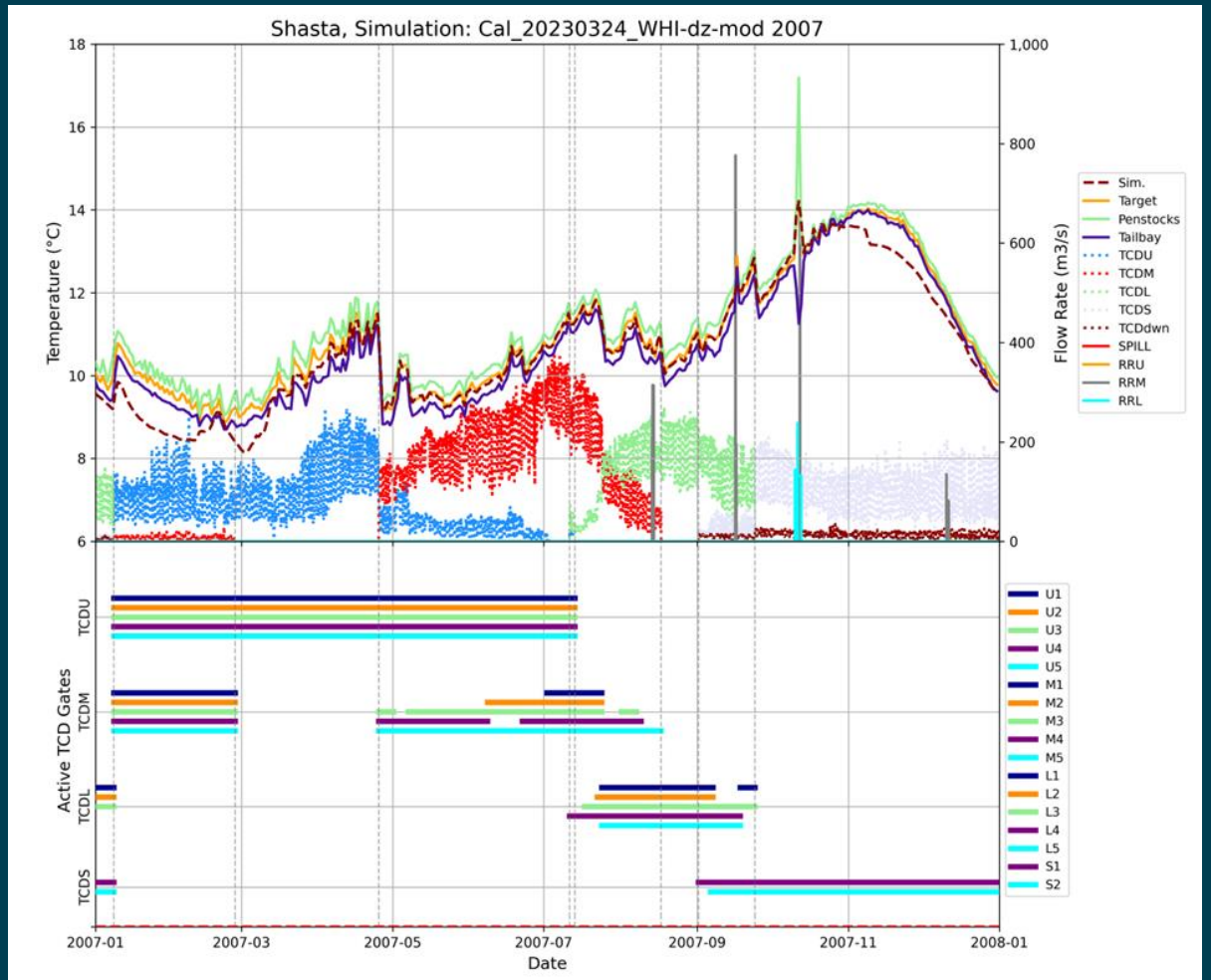
- HEC-ResSim
- 2007 Shasta Lake water temperature profile as an example



Statistic	1/10	2/6	3/6	4/5	5/15	6/5	7/17	8/1	9/5	9/17	10/2	10/24
Mean Bias (°C)	-0.60	-0.22	-0.12	-0.12	-0.24	-0.31	-0.30	-0.39	-0.51	-0.52	**-0.96***	**-1.3***
MAE (°C)	0.61	0.53	0.56	0.57	0.46	0.44	0.50	0.55	0.69	0.84	1.0	**1.3 ***
RMSE (°C)	0.69	0.59	0.63	0.76	0.59	0.59	0.70	0.82	1.0	1.3	**1.7***	**2.1***
NSE	**0.56***	**0.64***	**0.56***	0.85	0.97	0.98	0.98	0.98	0.98	0.96	0.89	0.69

Sacramento River Basin - Shasta Lake

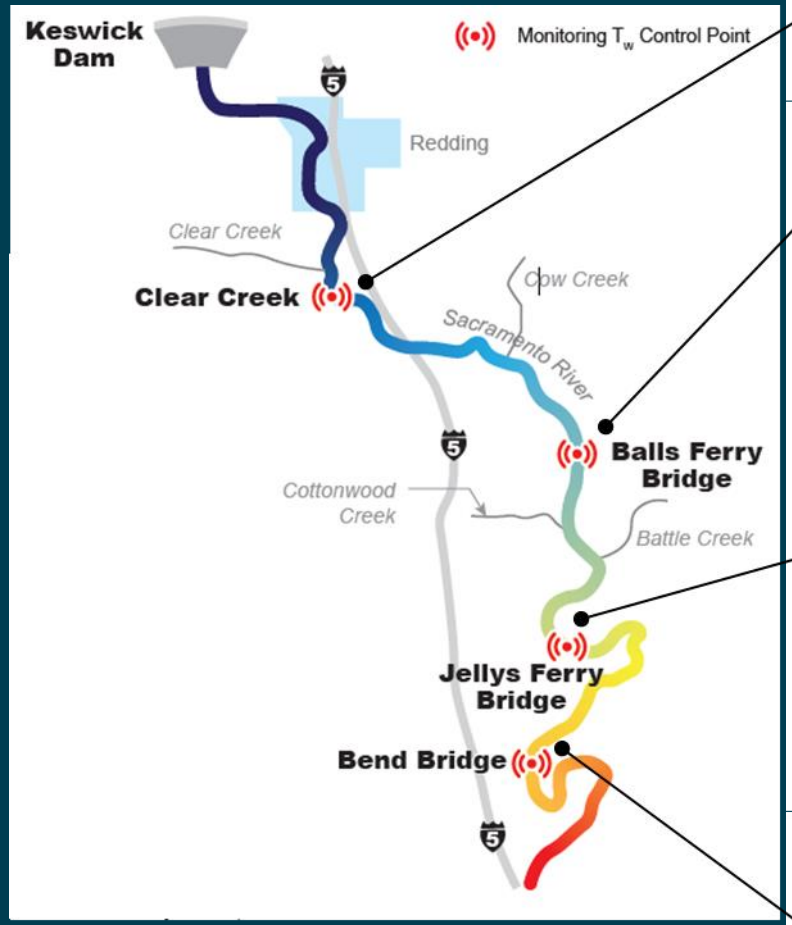
- HEC-ResSim
- 2007 Shasta Lake outflow temperature as an example

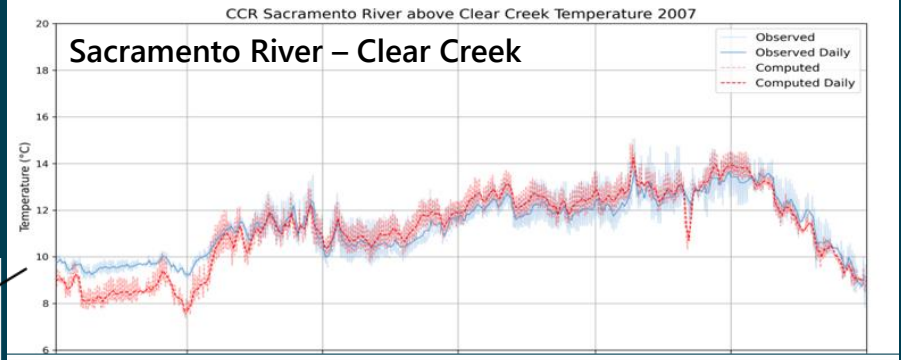


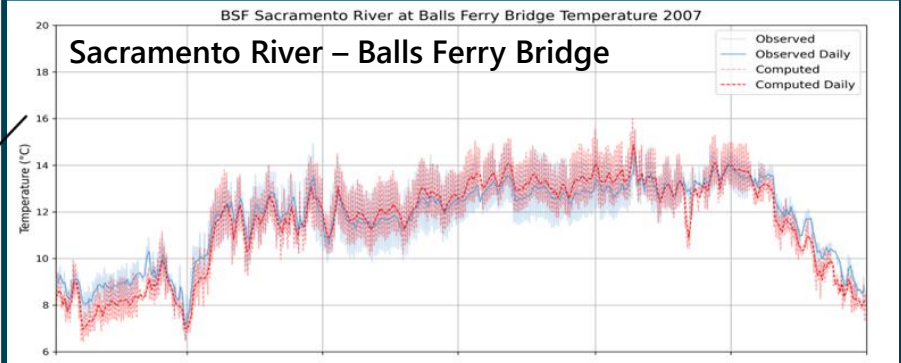
Statistic	2000	2001	2002	2003	2004	2005	2006	2007	2008
Mean Bias (◦C)	-0.02	-0.25	-0.26	-0.31	-0.20	-0.44	-0.33	**-0.25**	-0.27
MAE (◦C)	0.09	0.27	0.27	0.32	0.22	0.44	0.33	**0.28**	0.30
RMSE (◦C)	0.19	0.46	0.46	0.51	0.40	0.63	0.49	**0.46**	0.54
NSE	0.97	0.91	0.88	0.70	0.95	0.79	0.77	**0.90**	0.95

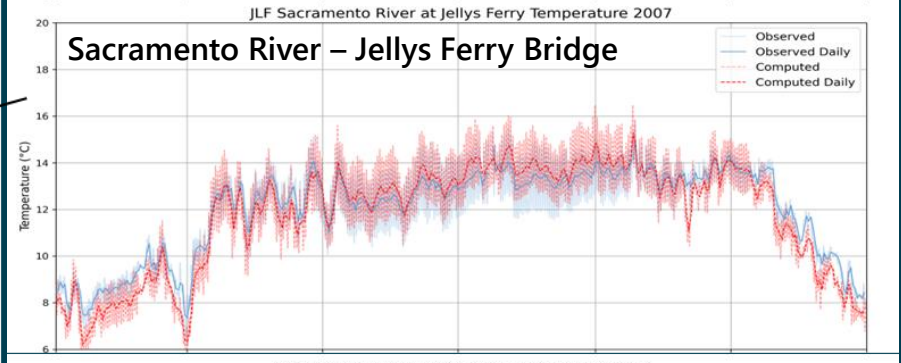
Sacramento River Basin – Sacramento River

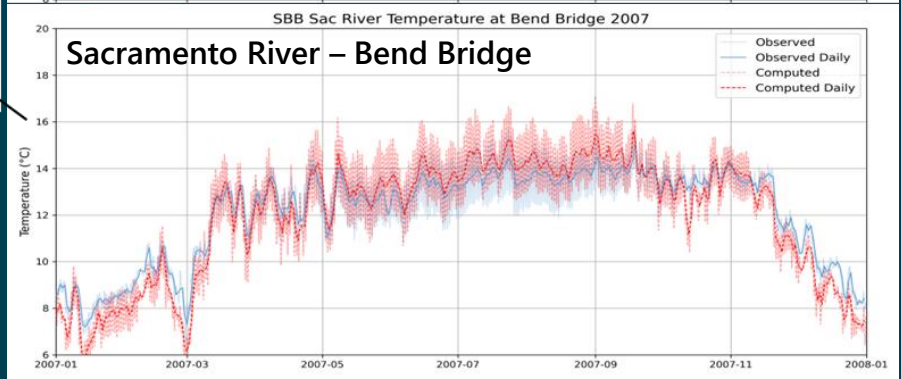
- HEC-ResSim
- 2007 Sacramento River water temperature at four control points as an example







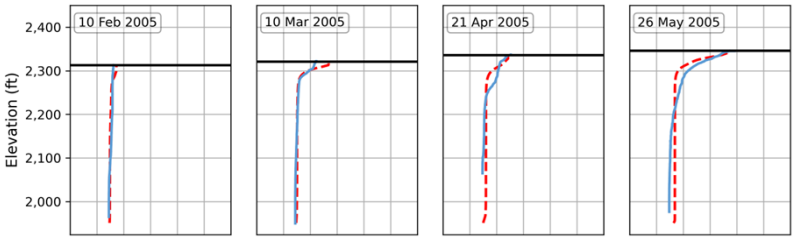


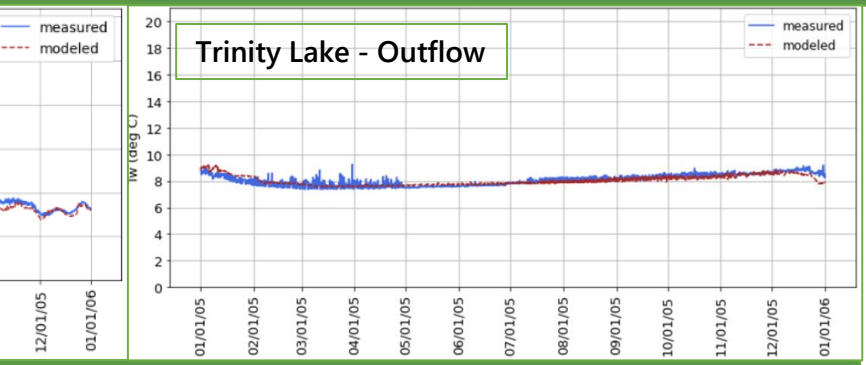


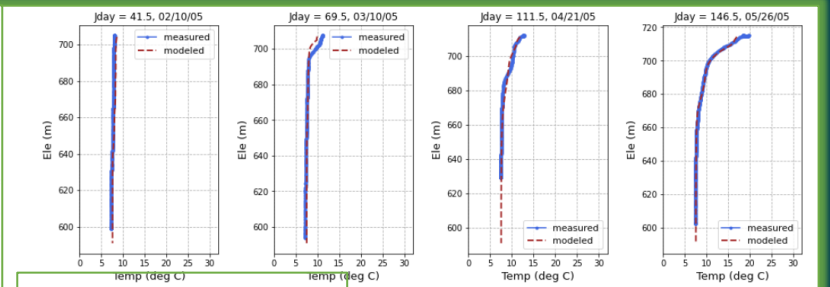
Trinity River Basin

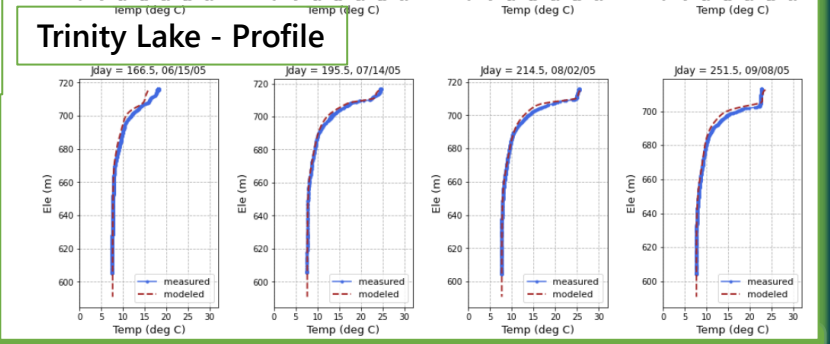
2005 results for an example

HEC-ResSim

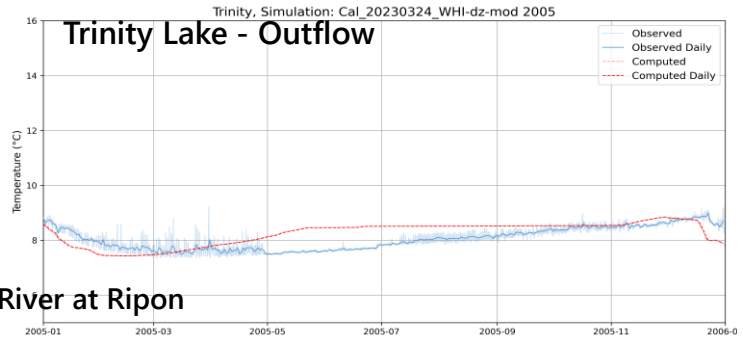


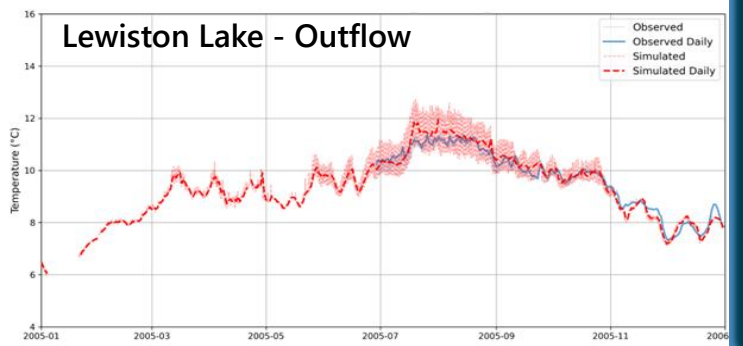




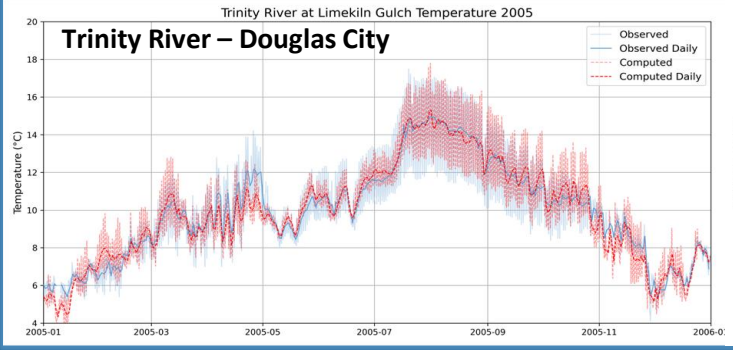


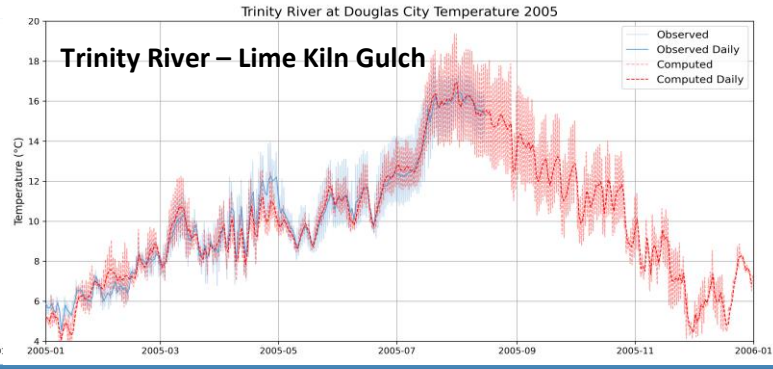
CE-QUAL-W2

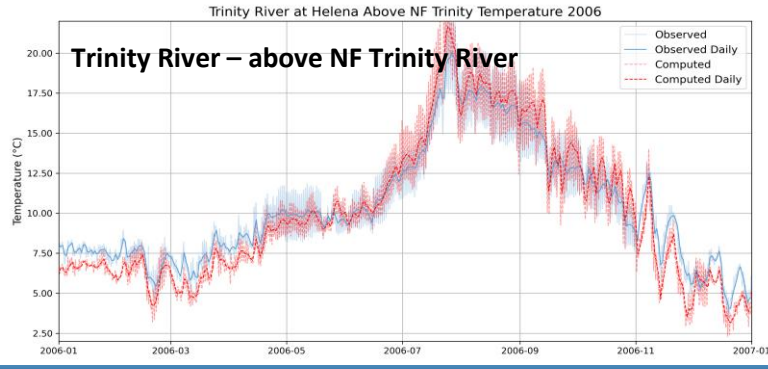




Stanislaus River at Ripon

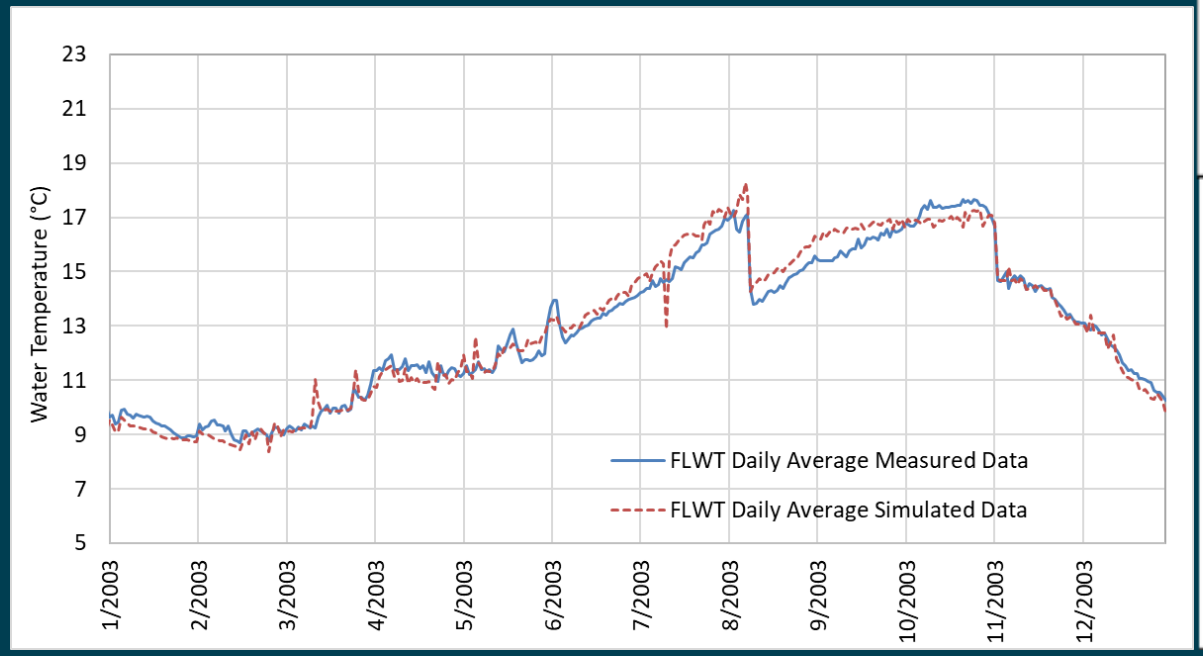


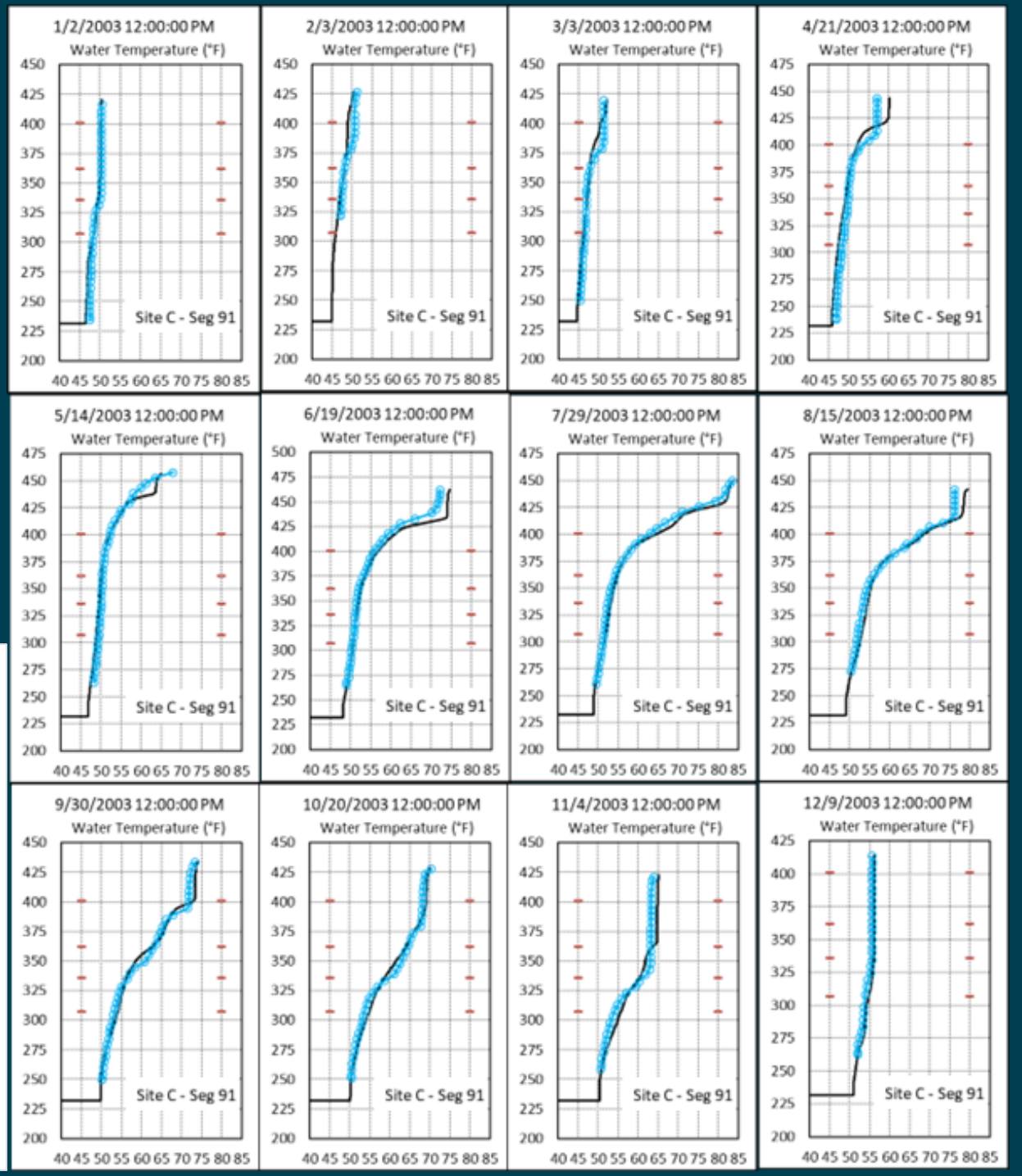




American River Basin - Folsom Lake

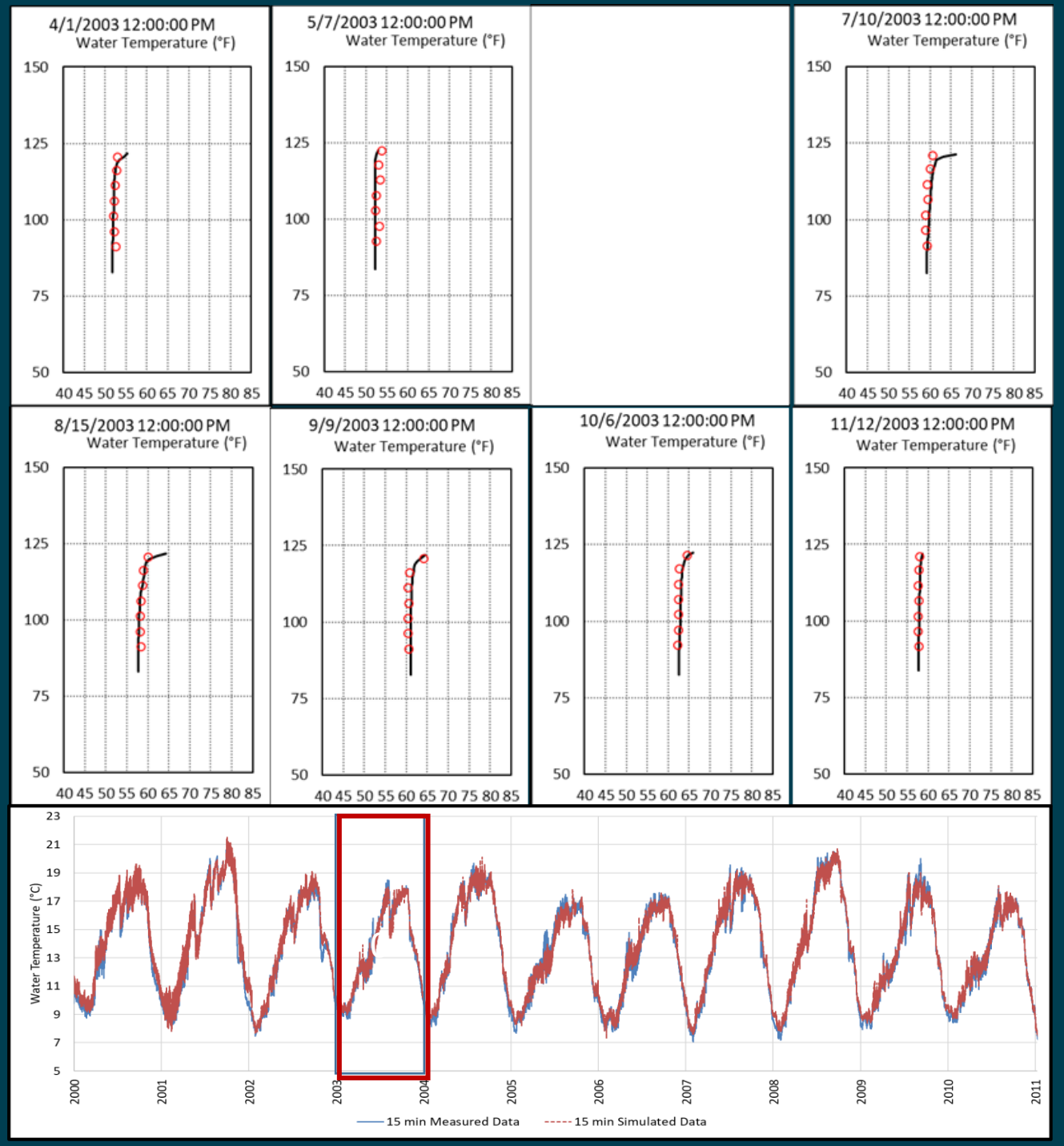
- CE-QUAL-W2
- 2003 Folsom Lake water temperature profile and outflow temperatures as an example





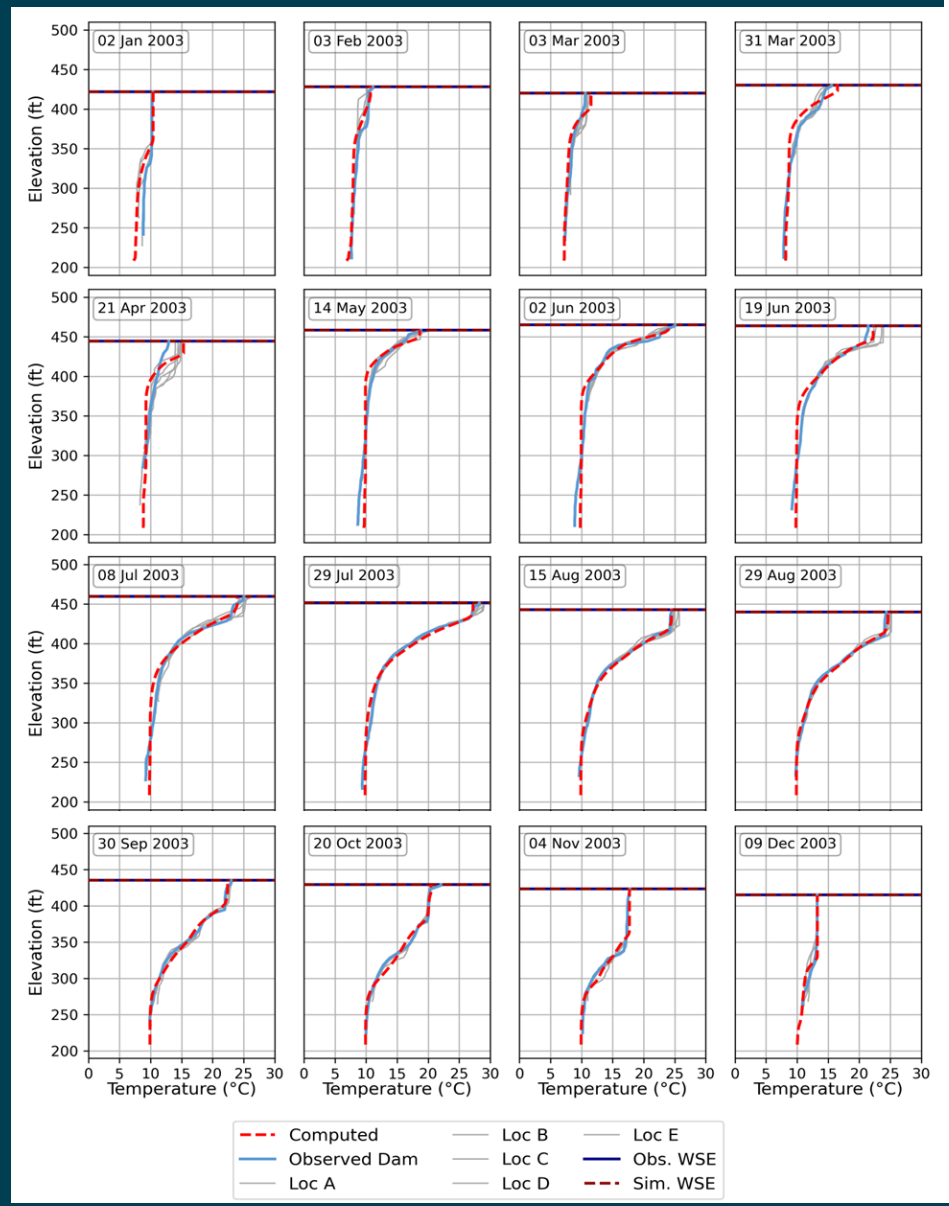
American River Basin - Lake Natoma

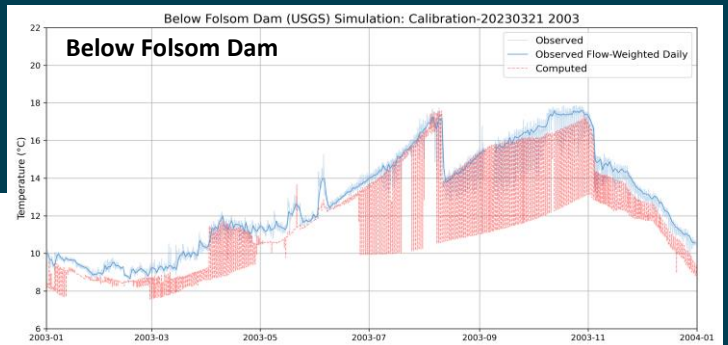
- CE-QUAL-W2
- 2003 Folsom Lake water temperature profile and outflow temperature as an example

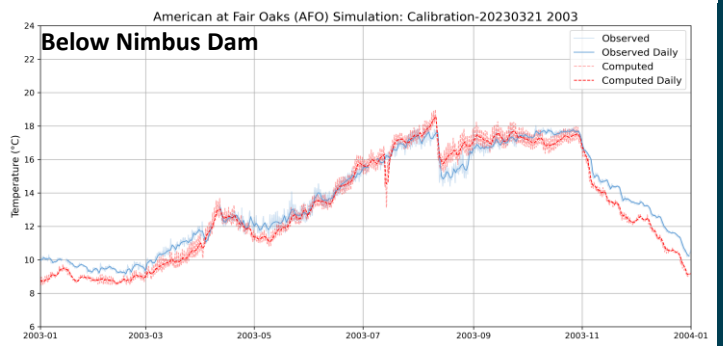


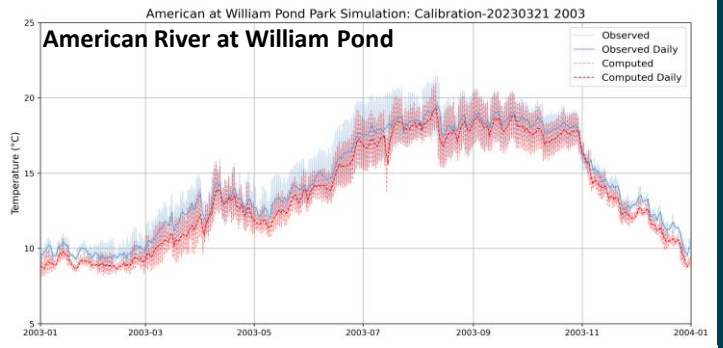
American River Basin – American River

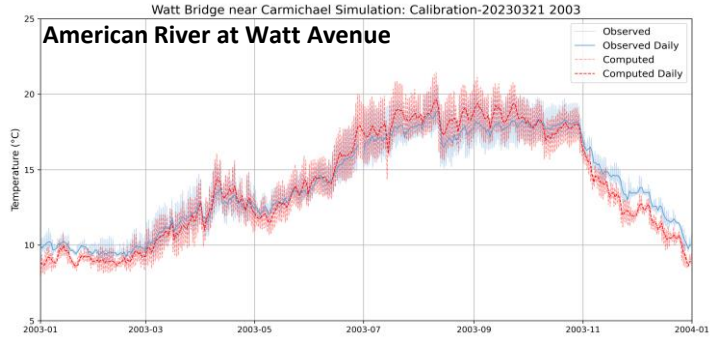
- HEC-ResSim
- Folsom Lake
  - Water temperature profile
  - Outflow temperature
- Nimbus Dam
- American River
  - At William Pond
  - At Watt Avenue
- 2003 results as an example





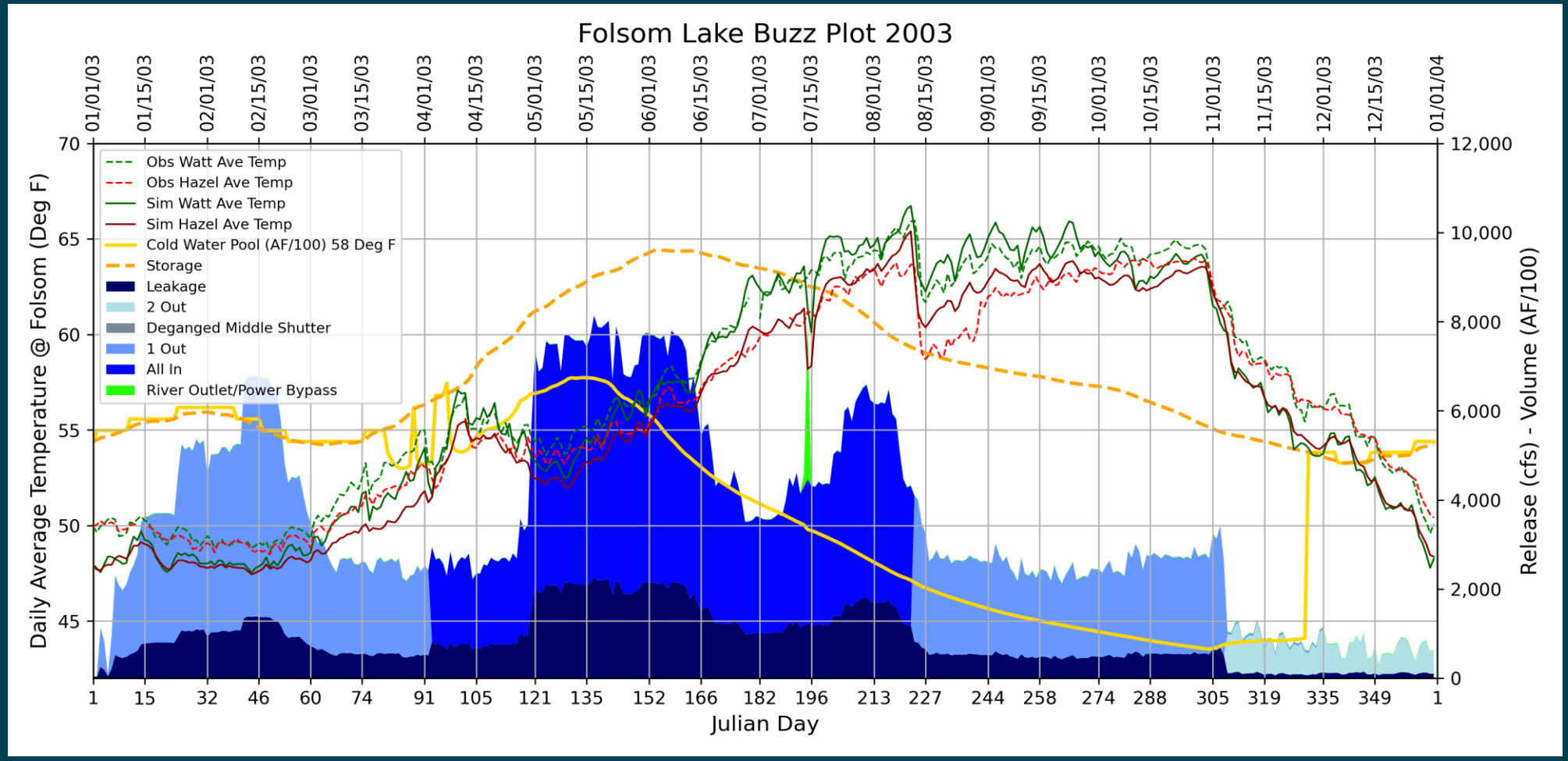






American River Basin – Customized Plots

- 2003 results as an example

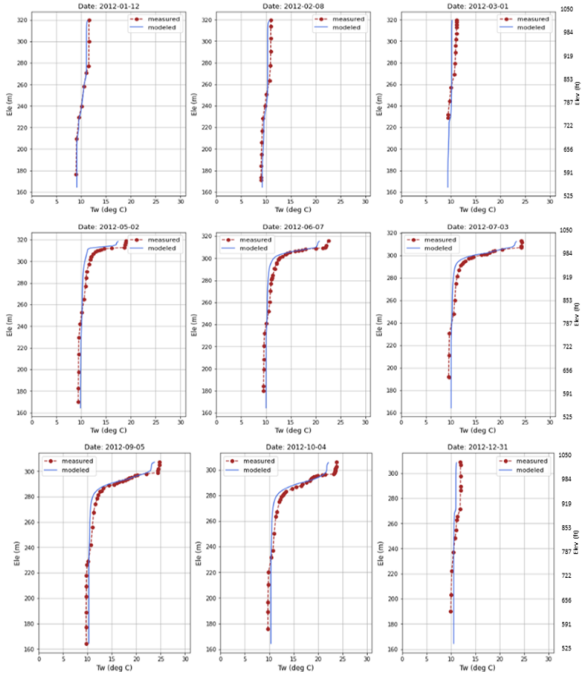


Stanislaus River Basin

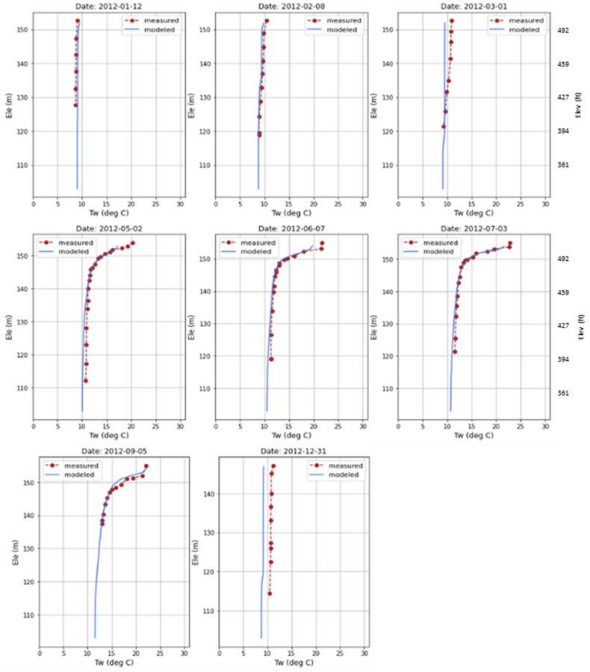
- 2012 results as an example

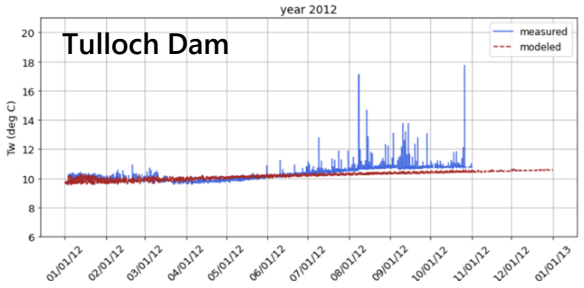
CE-QUAL-W2

New Melones Lake



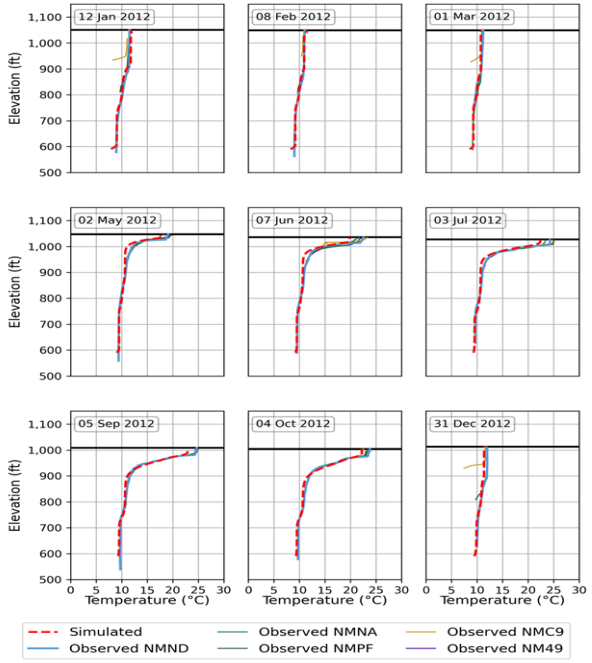
Tulloch Lake



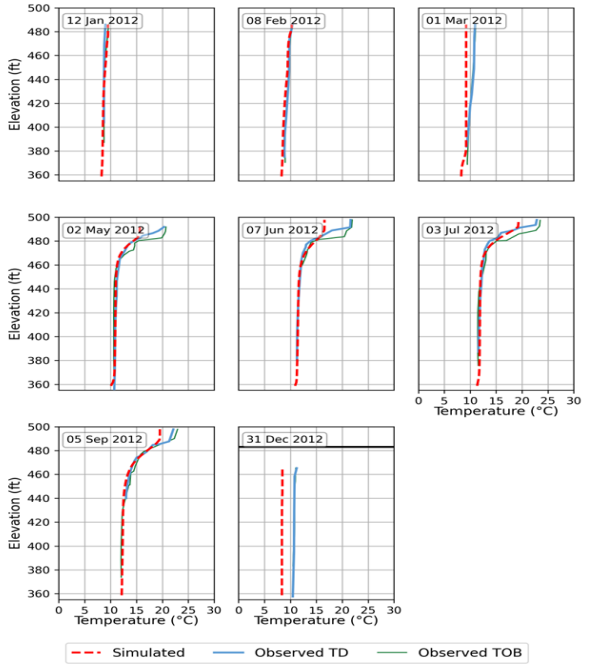


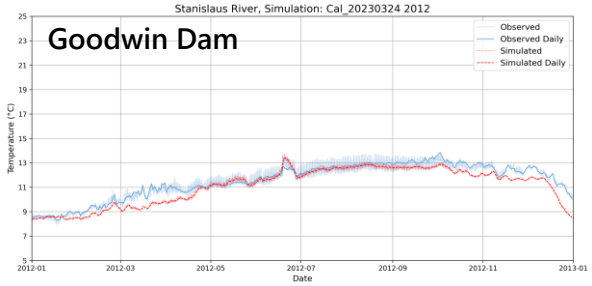
HEC-ResSim

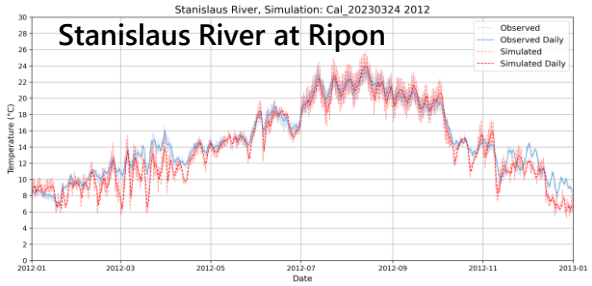
New Melones Lake



Tulloch Lake



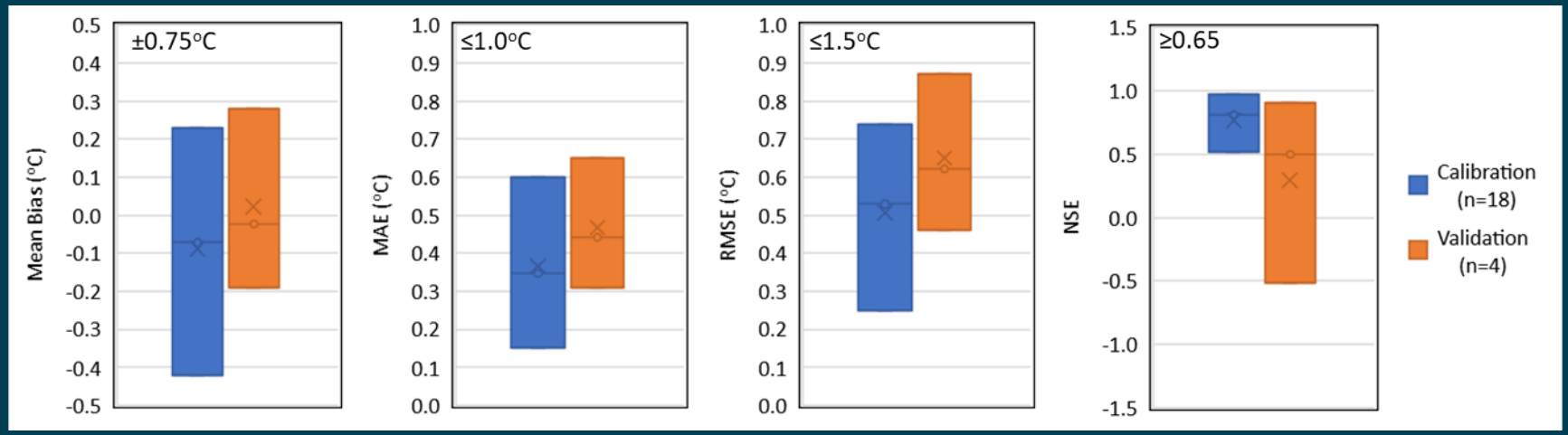




A Note on Validation

- Definition: Apply a calibrated model to a separate period without modifying calibrated parameters
- Period: With comparable hydrology, meteorology, and operations
- Assessments: Use the same model performance metrics for calibration
- Findings: Determine whether the calibrated model performs consistently

Example:
Shasta Lake Outflow Temperature Validation



Summary of Model Calibration Results

- Formal calibration and validation approach complete
- Identified recommendations
- Appropriate for use in WTMP

Conclusion: Calibrated models are ready for applications