



— BUREAU OF —
RECLAMATION

The Disappearing Act of Water:

Simulated changes in open water
evaporation across Upper Klamath Basin
as a result of agricultural development
and reservoir impoundment

CWEMF

April 2026

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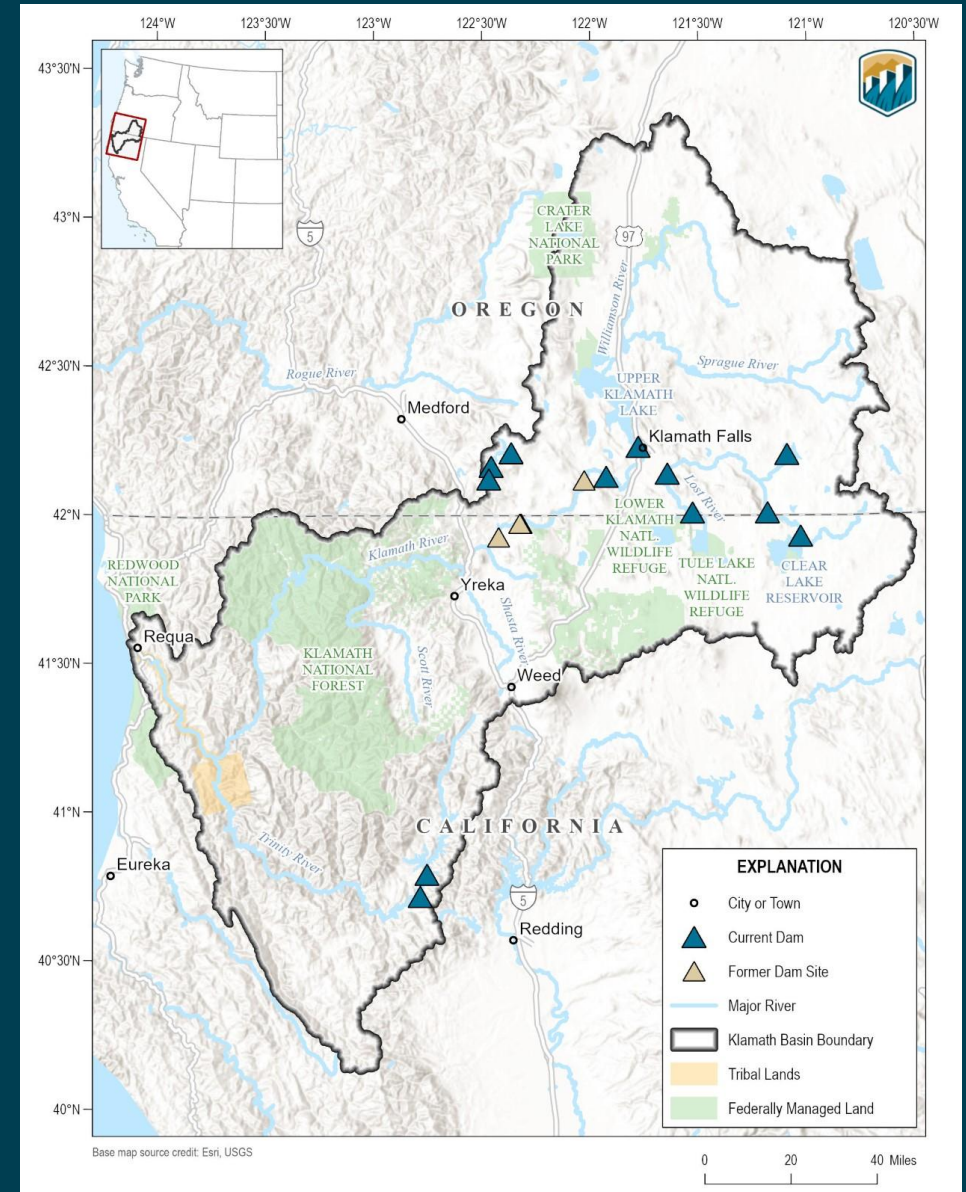
Upper Klamath Lake looking south (photo credit: Mikkelsen)

Outline

1. Objective of study – how does it fit in with the KNFS?
2. Model selection
3. Methods
4. Model validation
5. Results
6. Sources & quantification of uncertainty
7. Key take-aways



Klamath River Basin



Open Water Evaporation Modeling

Objective: To quantify how open water evaporation rates and volumes have changed between pre-development and current conditions from WY 1981 through WY 2020.

Lower Klamath NWR



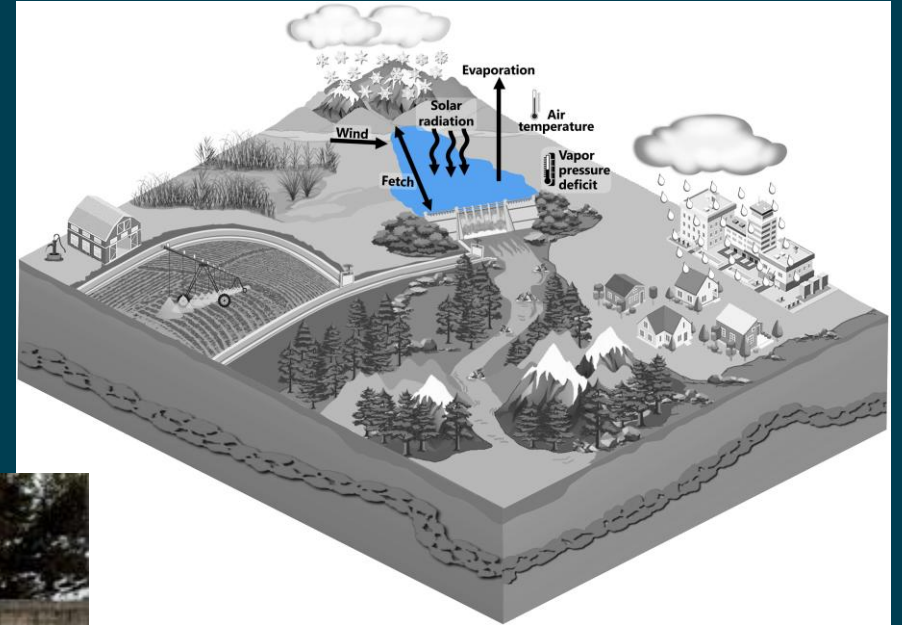
*photo credit: (<https://www.oregonlive.com/environment/2021/09/water-arrives-at-desperately-dry-lower-klamath-wildlife-refuge.html>)

Gerber Reservoir Dam



*photo credit: USBR.gov

Open Water Evaporation in the KNFS



Daily Lake Evaporation Model (DLEM)

Heat storage effect:

$$\Delta U = \bar{h}\rho c[T_w(t) - T_w(t - \Delta t)]$$

Wind function for fetch effect:

$$f(u_2) = \lambda_v(2.33 + 1.65u_2)L^{-0.1}$$

Penman Equation
$$E = \frac{s(R_n - \Delta U) + \gamma f(u_2)\delta_e}{\lambda_v(s + \gamma)}$$

s : slope of the saturation vapor pressure curve ($\text{kPa}\cdot^\circ\text{C}^{-1}$)

R_n : net radiation ($\text{MJ}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$)

γ : psychrometric constant ($\text{kPa}\cdot^\circ\text{C}^{-1}$)

$f(u_2)$: wind function ($\text{s}\cdot\text{m}^{-1}$); u_2 : wind speed at 2m

δ_e : vapor pressure deficit (kPa)

λ_v : latent heat of vaporization ($\text{MJ}\cdot\text{kg}^{-1}$)

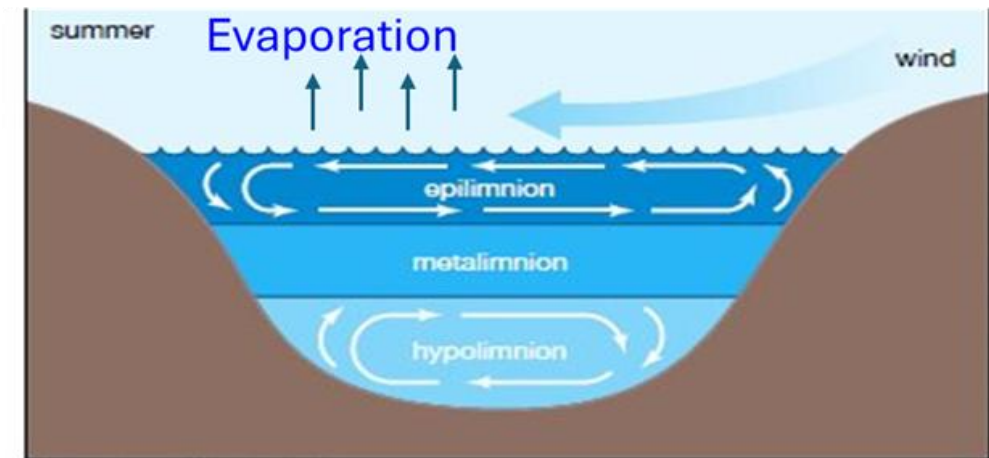
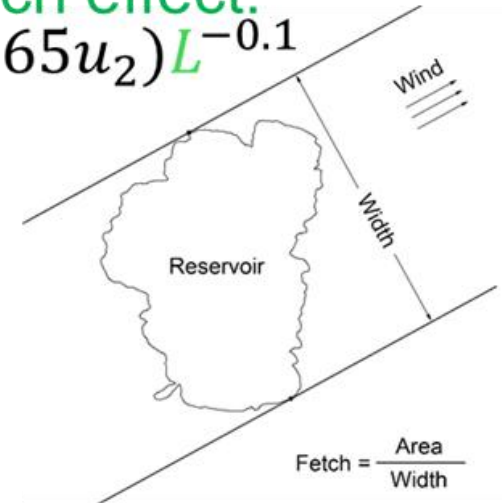
$\bar{h}$: average depth

ρ : water density

c : specific heat of water

L : fetch length

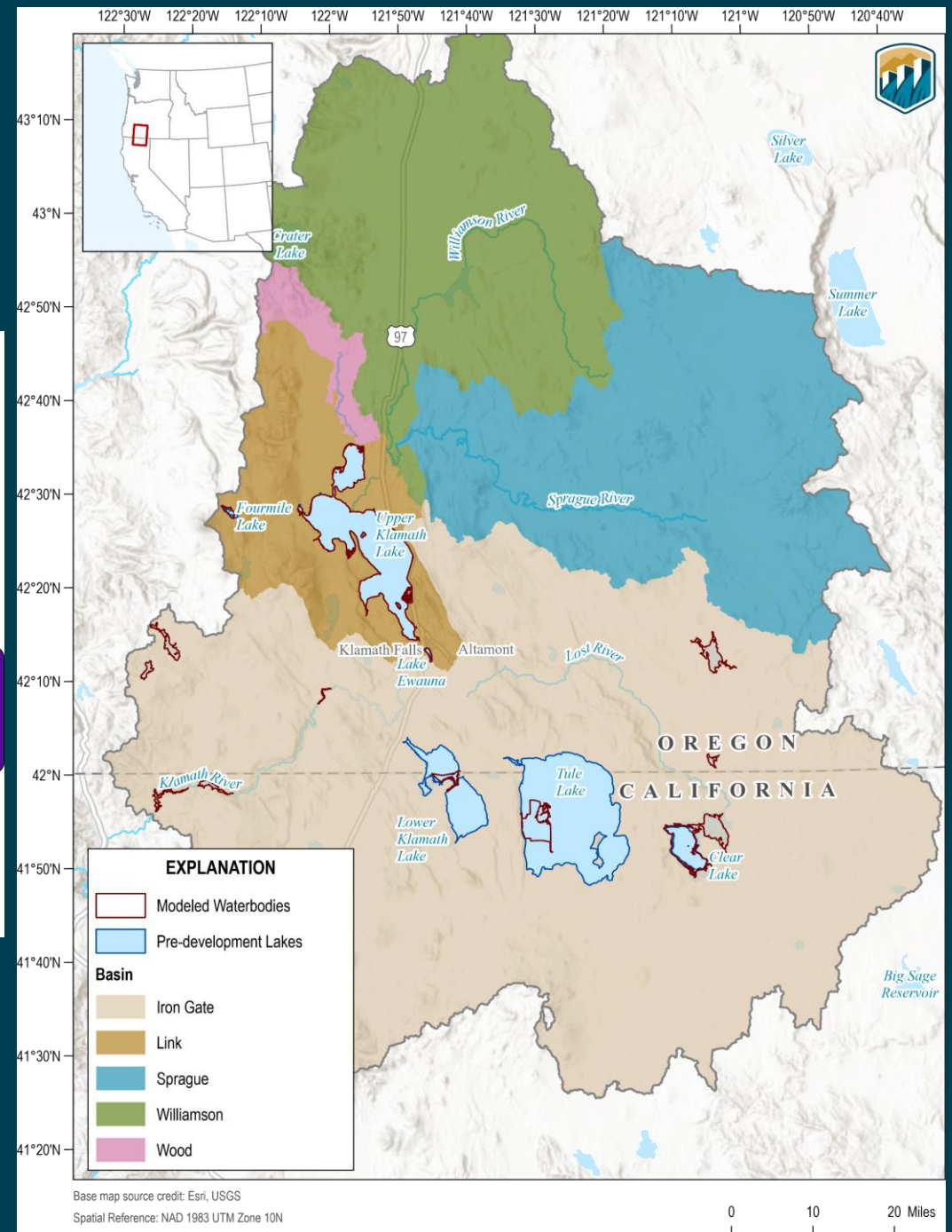
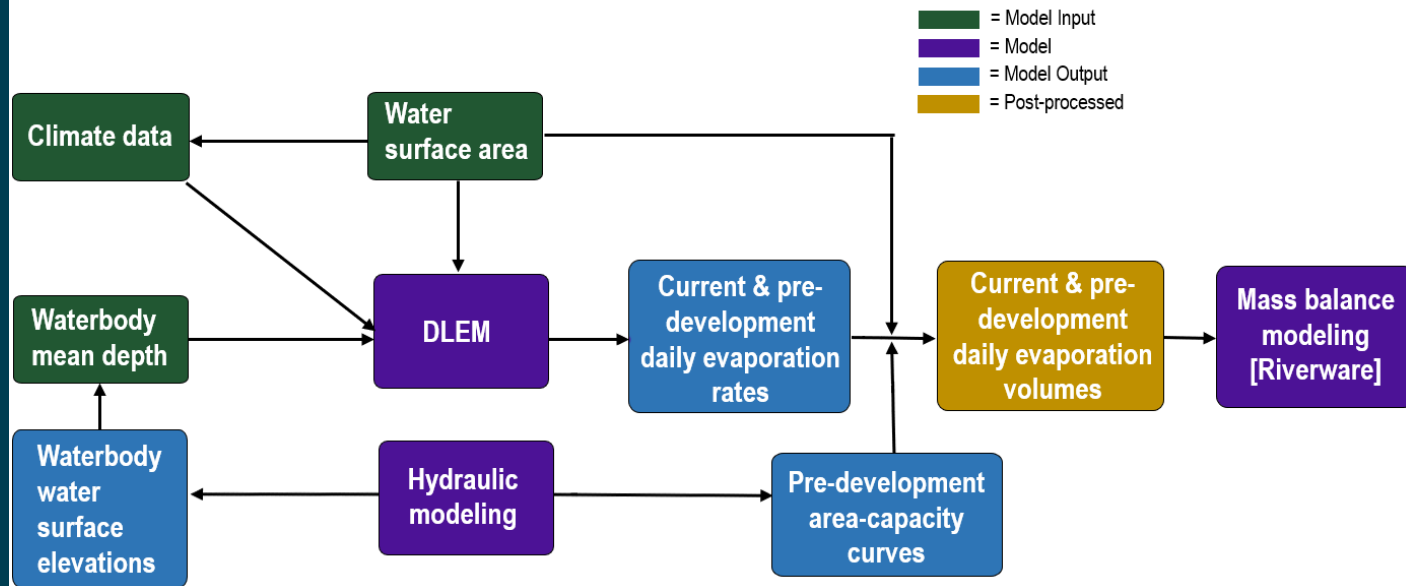
$T_w(t)$: water temperature at time step $t=1\text{day}$



Zhao and Gao, Remote Sensing of Environment, 2019
Zhao et al., Water Resources Research, 2024

Methods

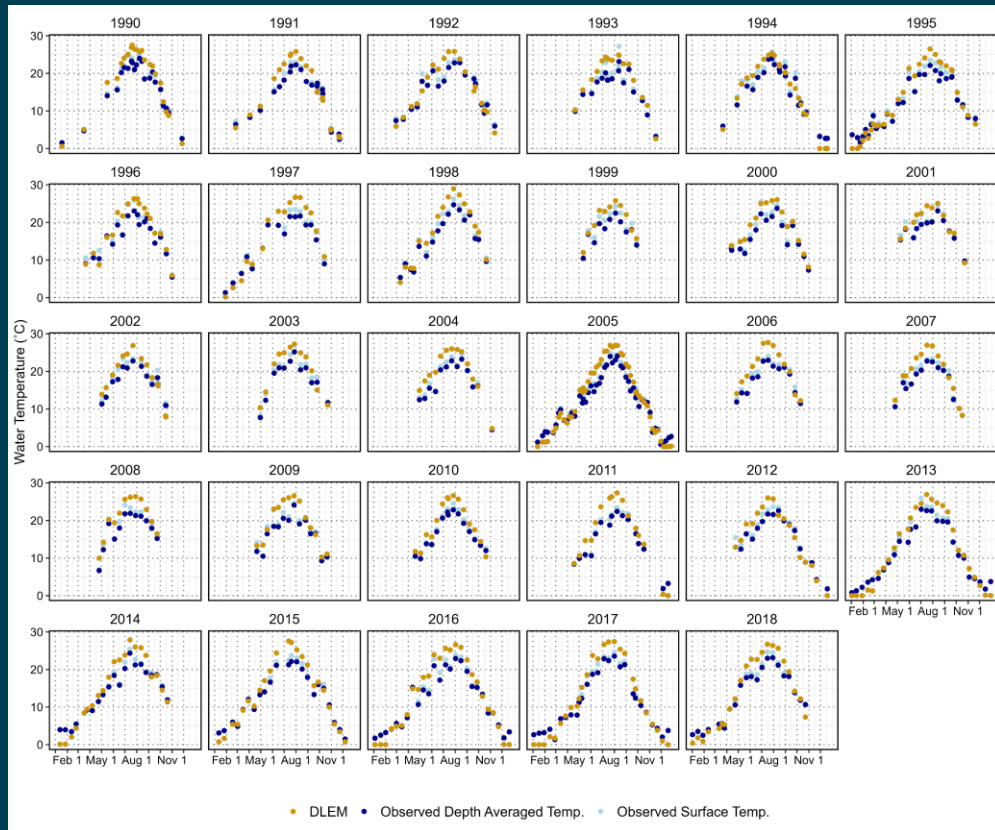
Open Water Evaporation



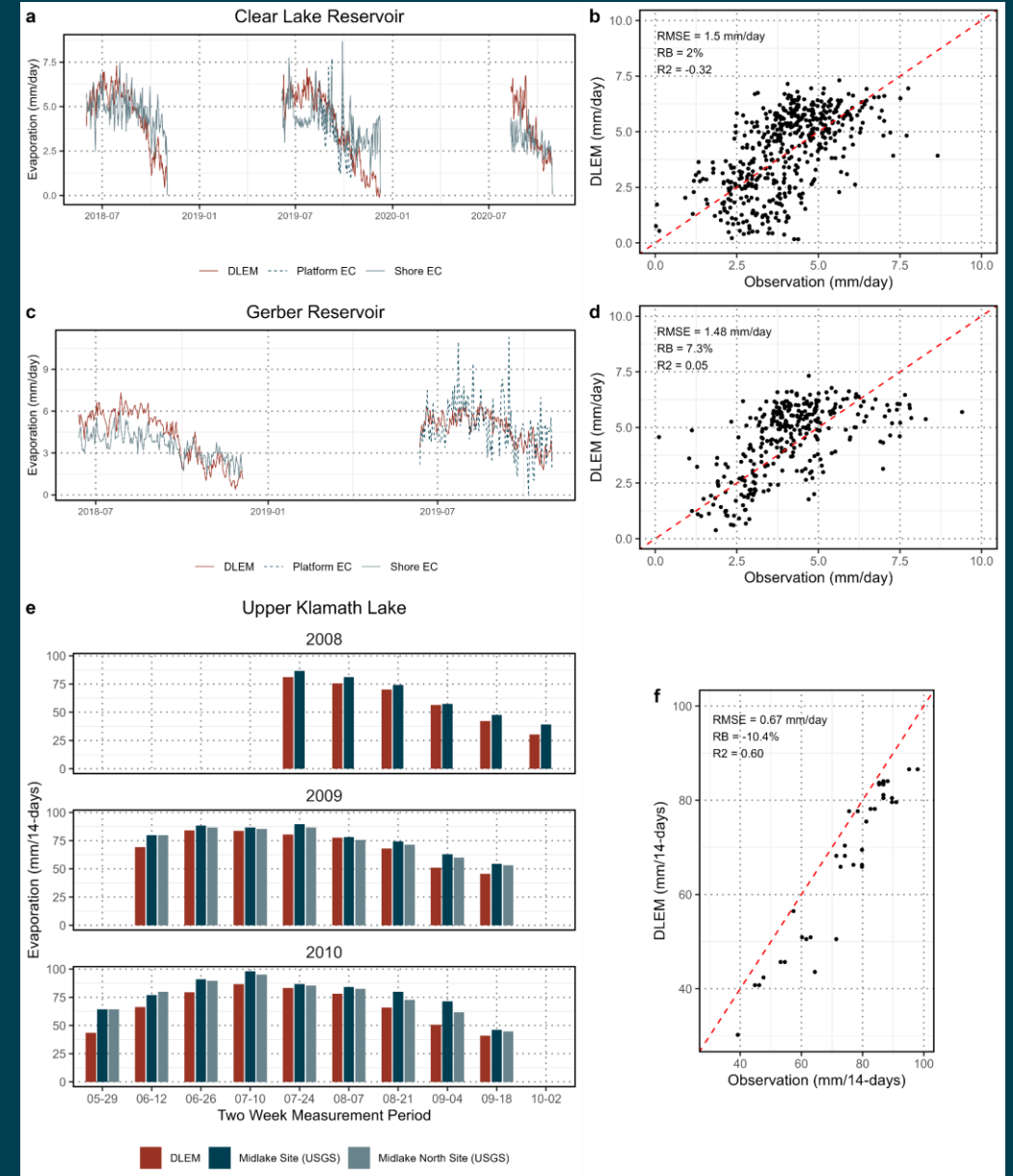
Model Validation

Compared DLEM-simulated water temperatures to observations at Upper Klamath Lake –

- High temperature bias in summer
- Low temperature bias in winter



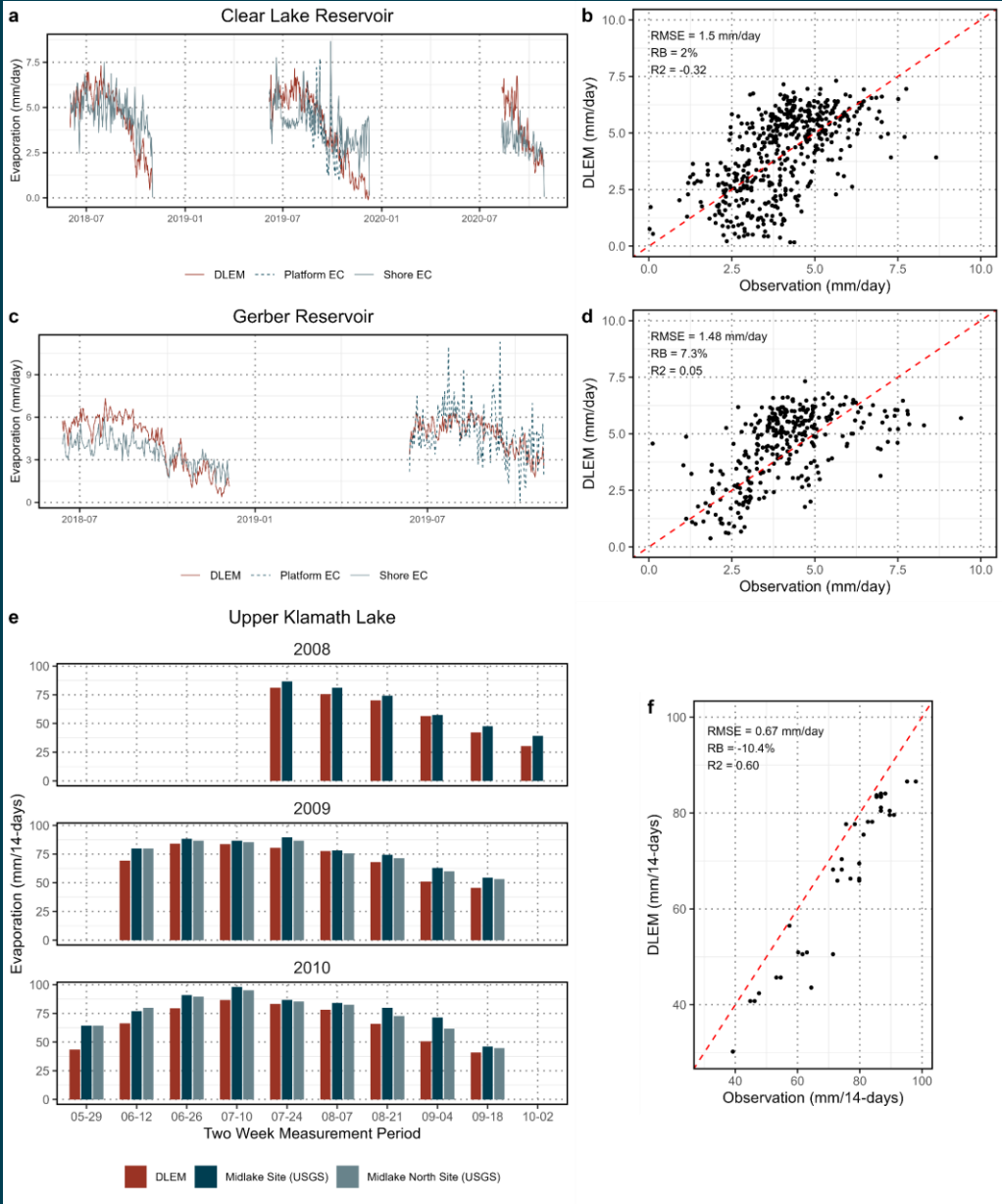
- Compared modeled evaporation rates to observations at Upper Klamath Lake, Gerber, and Clear Lake reservoirs



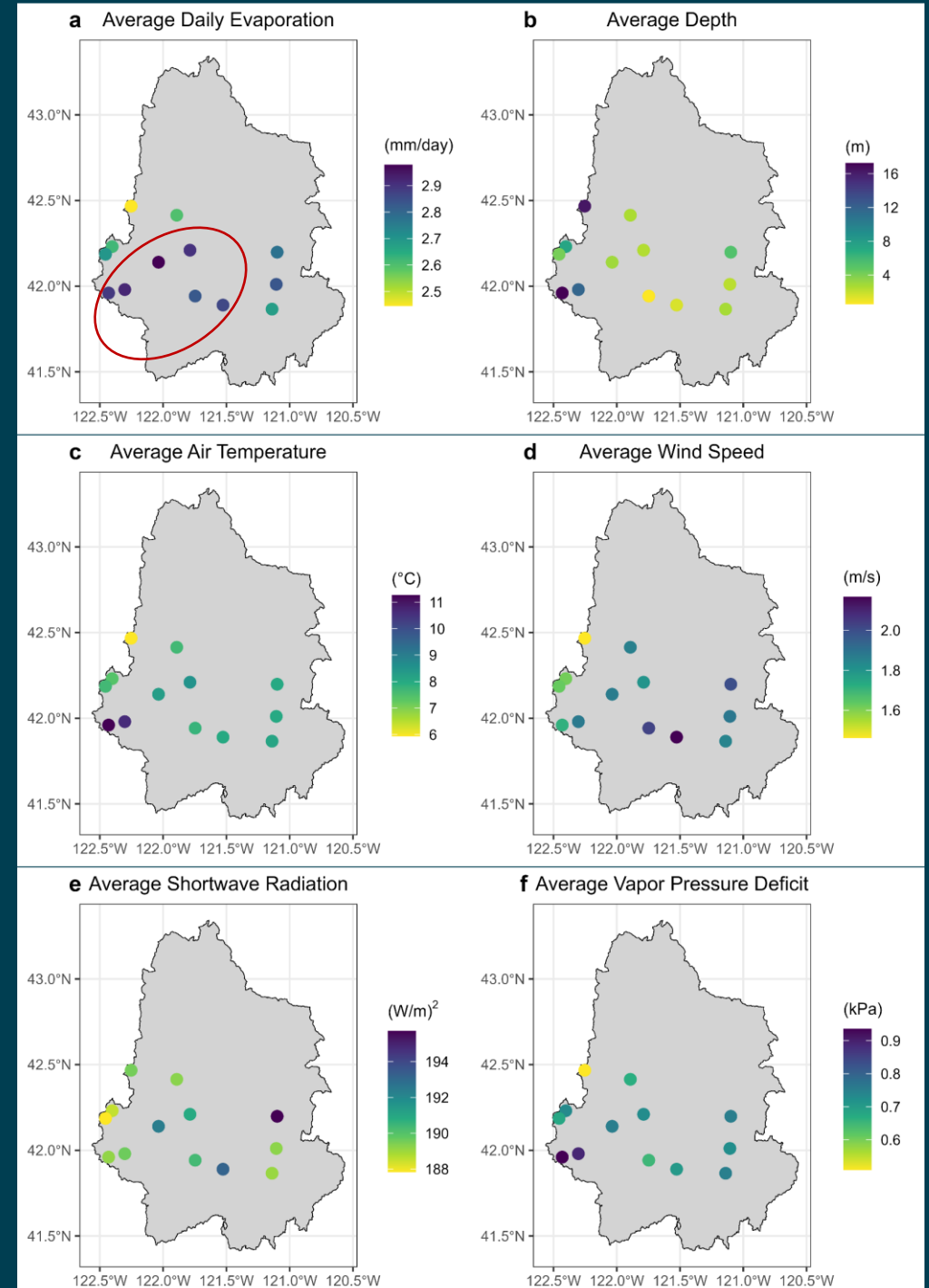
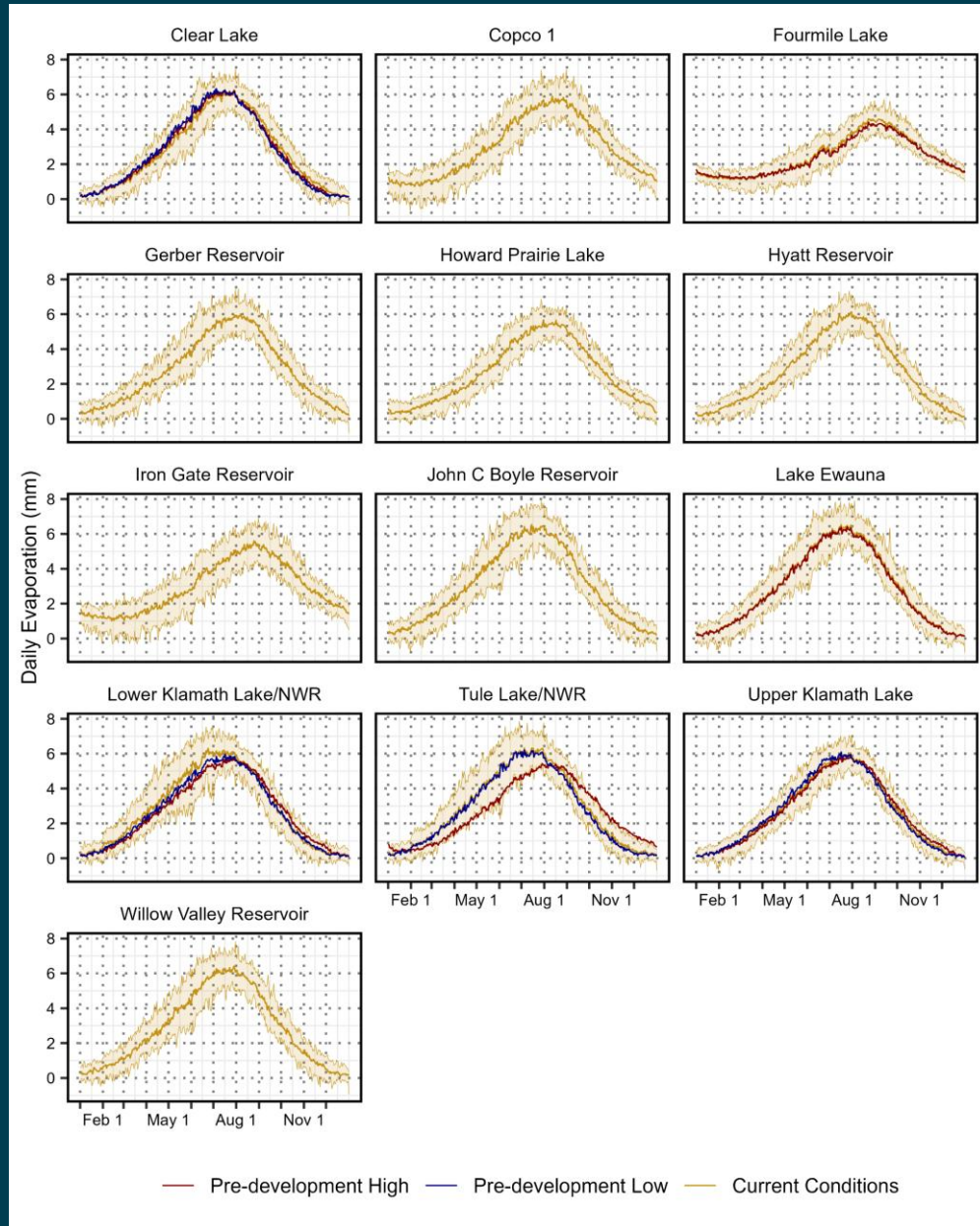
Model Validation

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Reservoir or Lake	Field Study	Observation Duration	DLEM Average MAE (in/day)	CRLE Average MAE (in/day)
Upper Klamath Lake	Stannard et al. 2013	2-week periods during the summer of 2008, 2009, 2010	0.013	0.017
Clear Lake Reservoir	Reclamation 2021a	Monthly periods during summer and fall months in 2018 and 2019	0.044	0.045
Gerber Reservoir	Reclamation 2021a		0.041	0.050

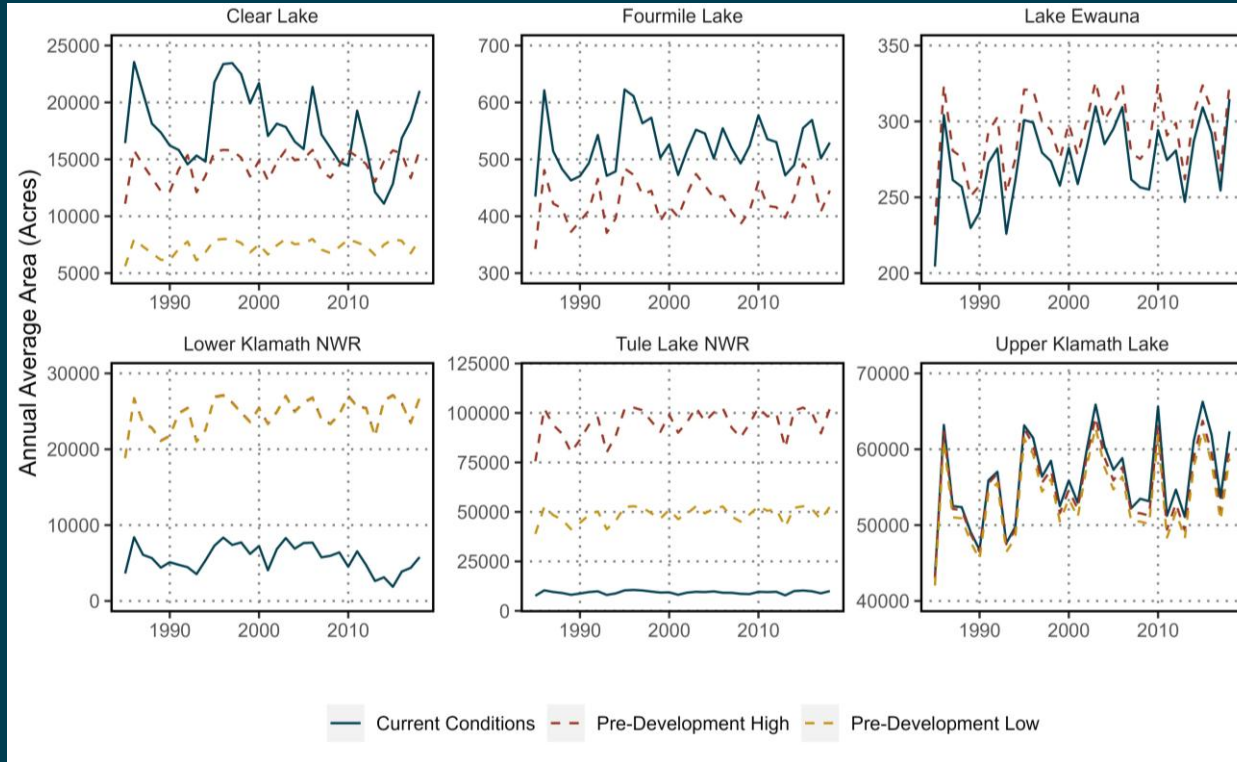


Results – Evaporation Rates

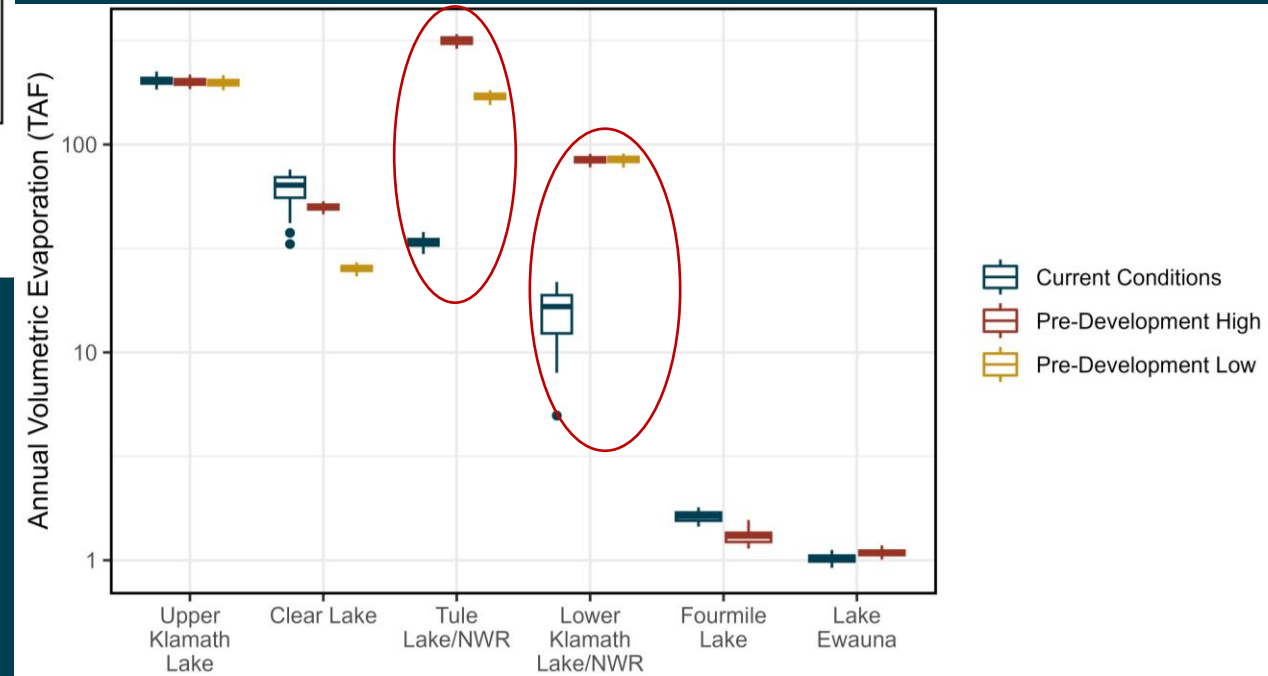


Results – Evaporation Volumes

Timeseries of Annual Average Waterbody Area

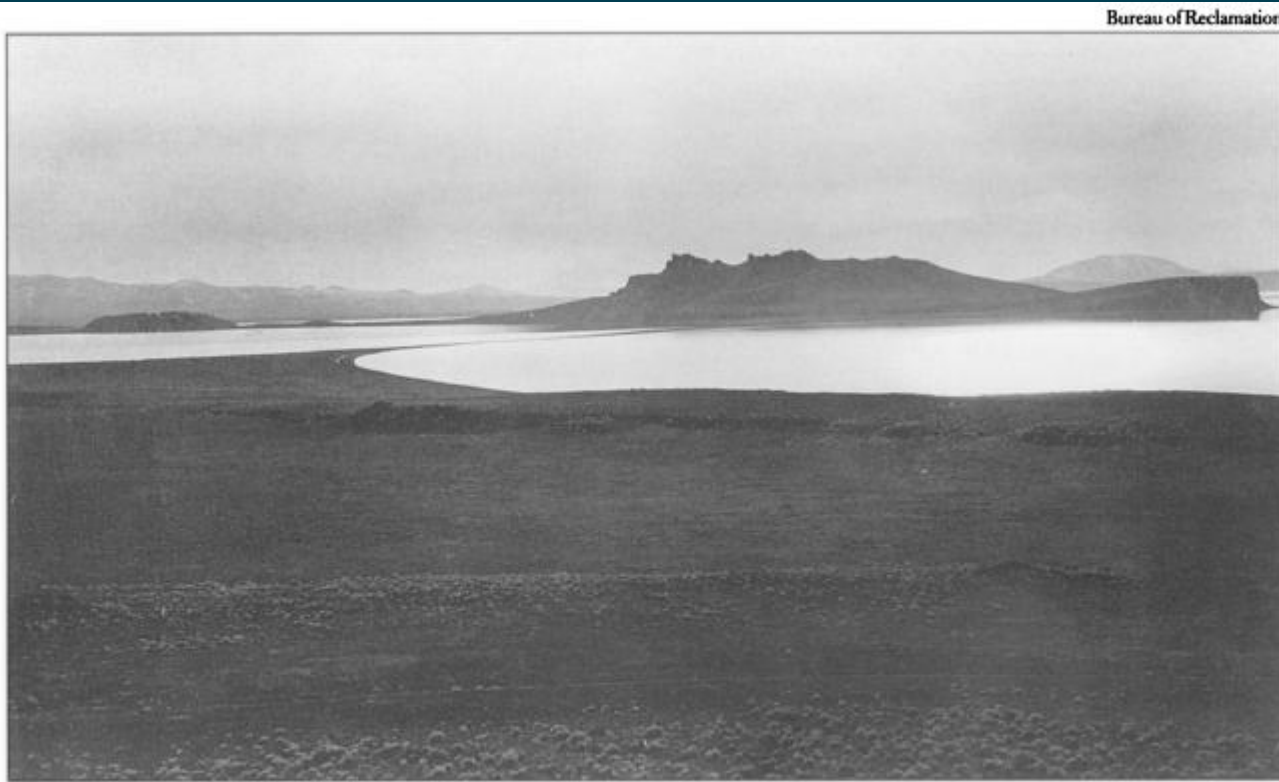


Annual Evaporation Volumes

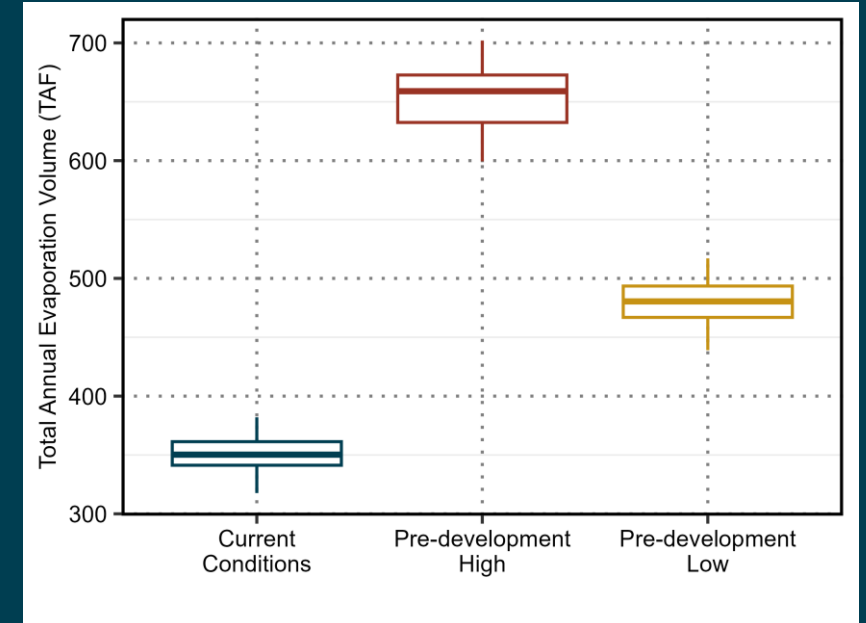
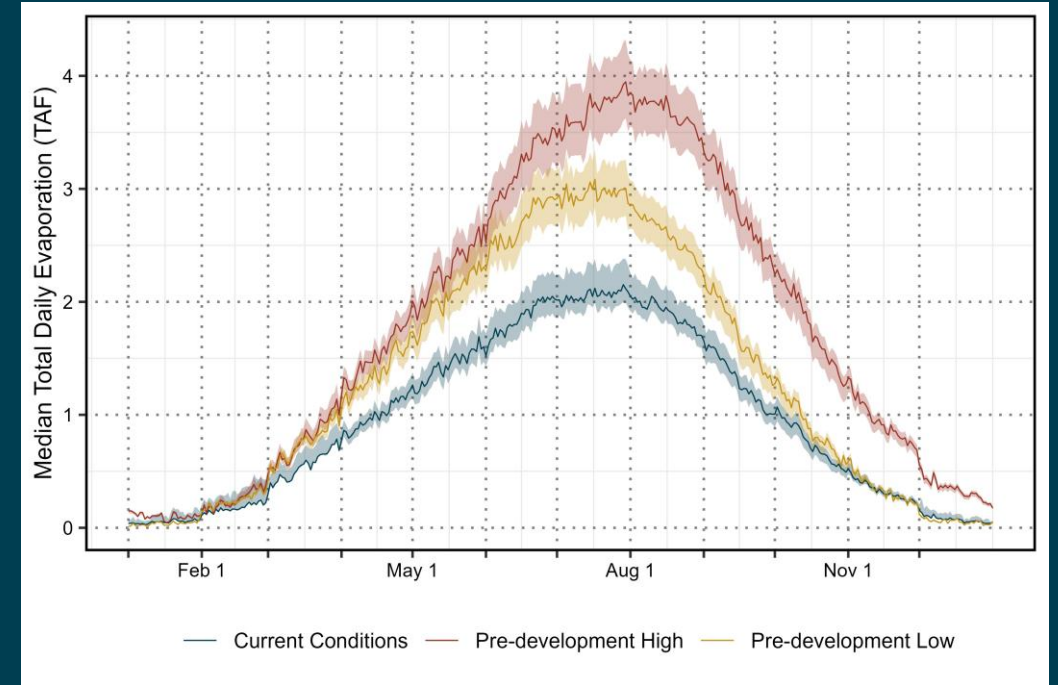


Results – Evaporation Volumes

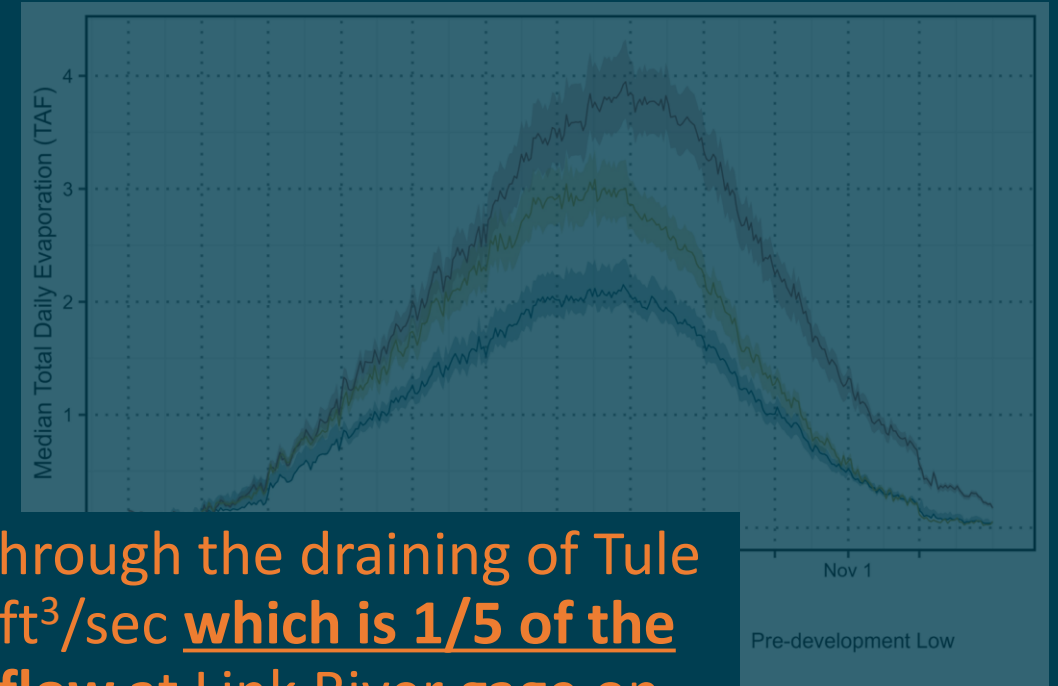
Tule Lake at high water levels in 1908



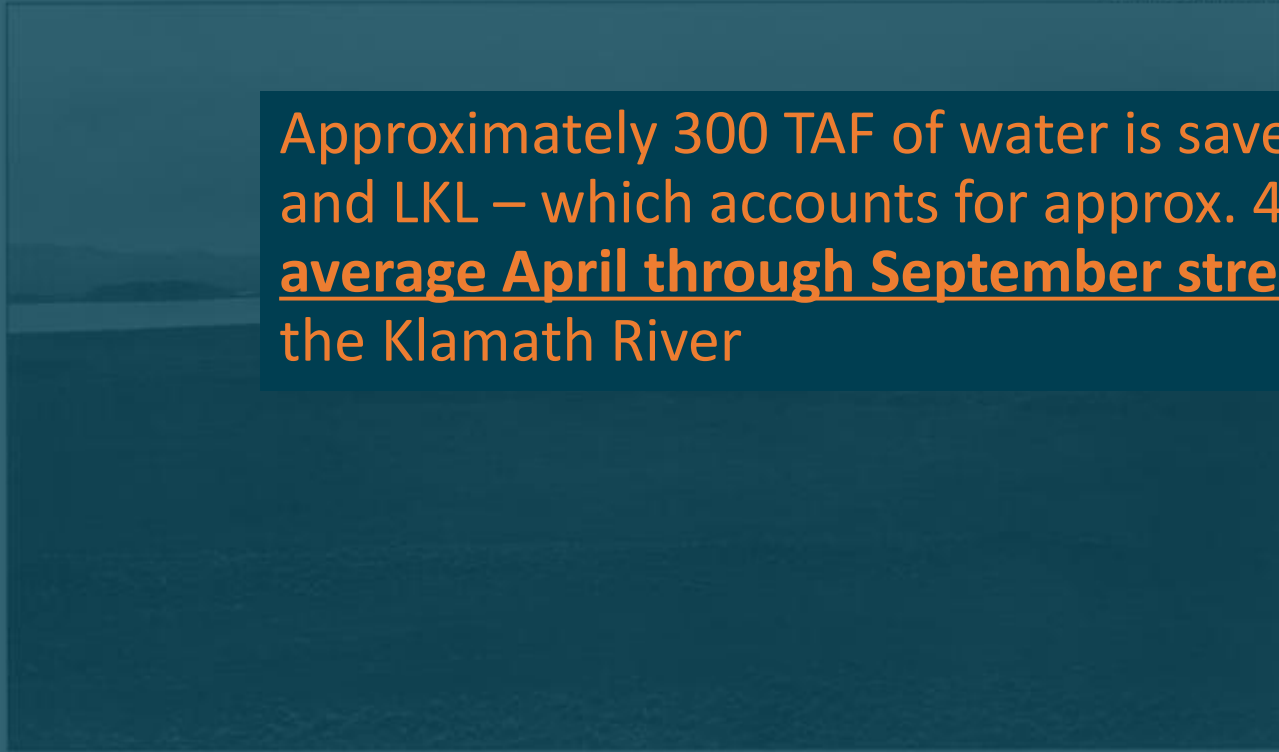
When Tule Lake was at high water levels, as it was when this 1908 photograph was taken, it was not surrounded by extensive marshes, unlike nearby Lower Klamath Lake. This view looks east across Tule Lake before the Klamath Irrigation Project “de-watered” the lake.



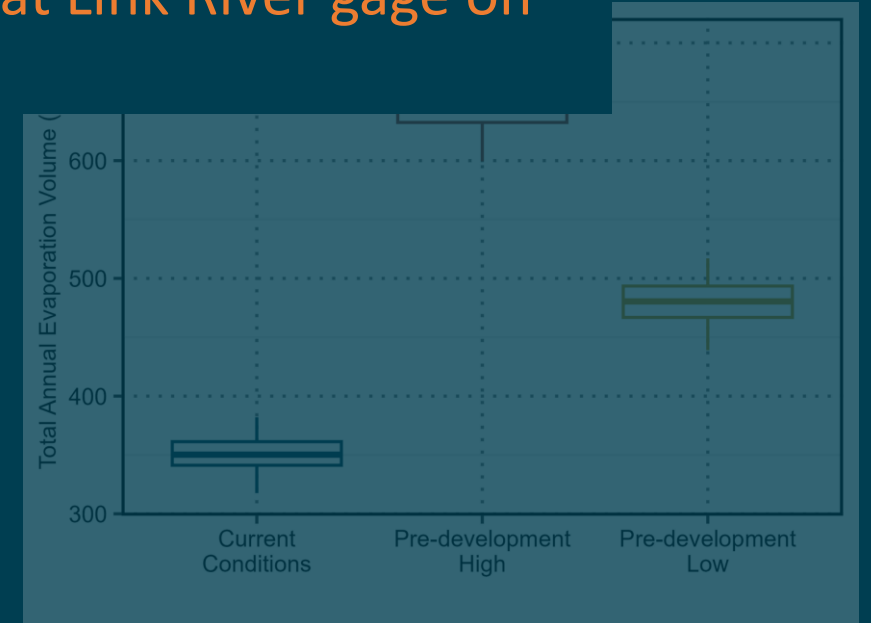
Results – Evaporation Volumes



Approximately 300 TAF of water is saved through the draining of Tule and LKL – which accounts for approx. 468 ft³/sec which is 1/5 of the average April through September streamflow at Link River gage on the Klamath River



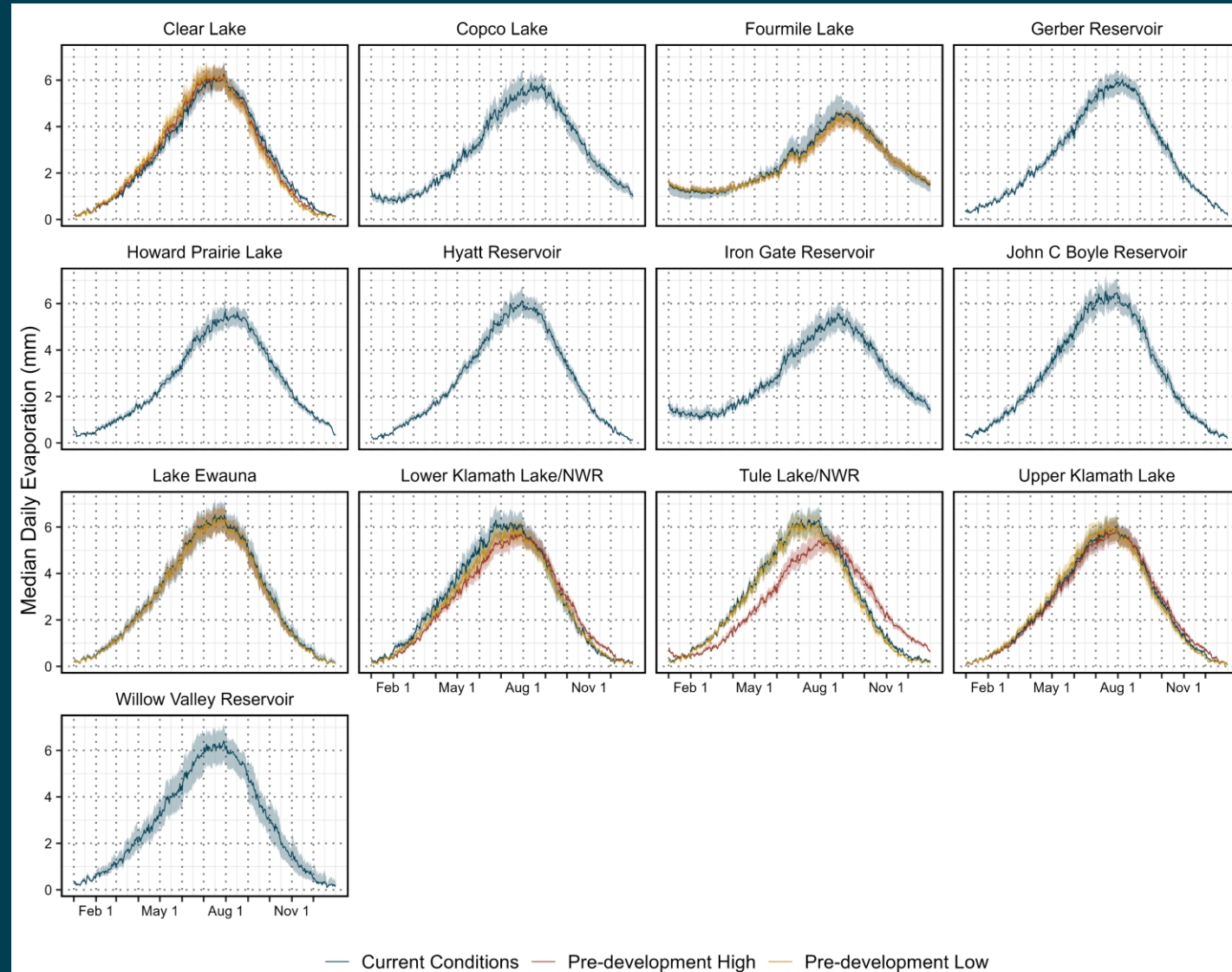
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Uncertainty Analysis

Quantified uncertainty individually for each waterbody and each month of the year based on:

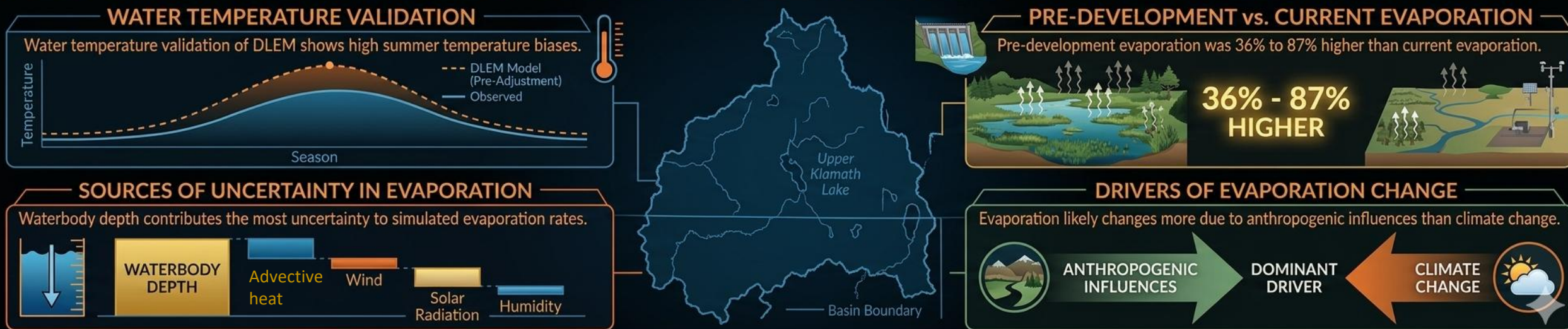
1. Reservoir depth
2. Forcing data biases
3. Advective heat transport



Key Takeaways

- Water temperature validation of DLEM shows high summer temperature biases.
- Pre-development evaporation volume was 36% to 87% higher than current evaporation.
- Waterbody depth contributes the most uncertainty to simulated evaporation rates.
- Evaporation likely changes more due to anthropogenic influences than climate change.

KEY HYDROLOGICAL MODELING FINDINGS: UPPER KLAMATH BASIN



**My first AI generated graphical image :)*

- Questions?
- Contact: kmikkelson@usbr.gov



In Review: Mikkelson, K.M., Holman K.D., Lenters, L.D. 2026. Changes in open water evaporation across Upper Klamath River Basin as a result of agricultural development and reservoir impoundment. *Journal of Hydrology: Regional Studies*.