



— BUREAU OF —
RECLAMATION

The Situation was Fluid (Pun Intended):

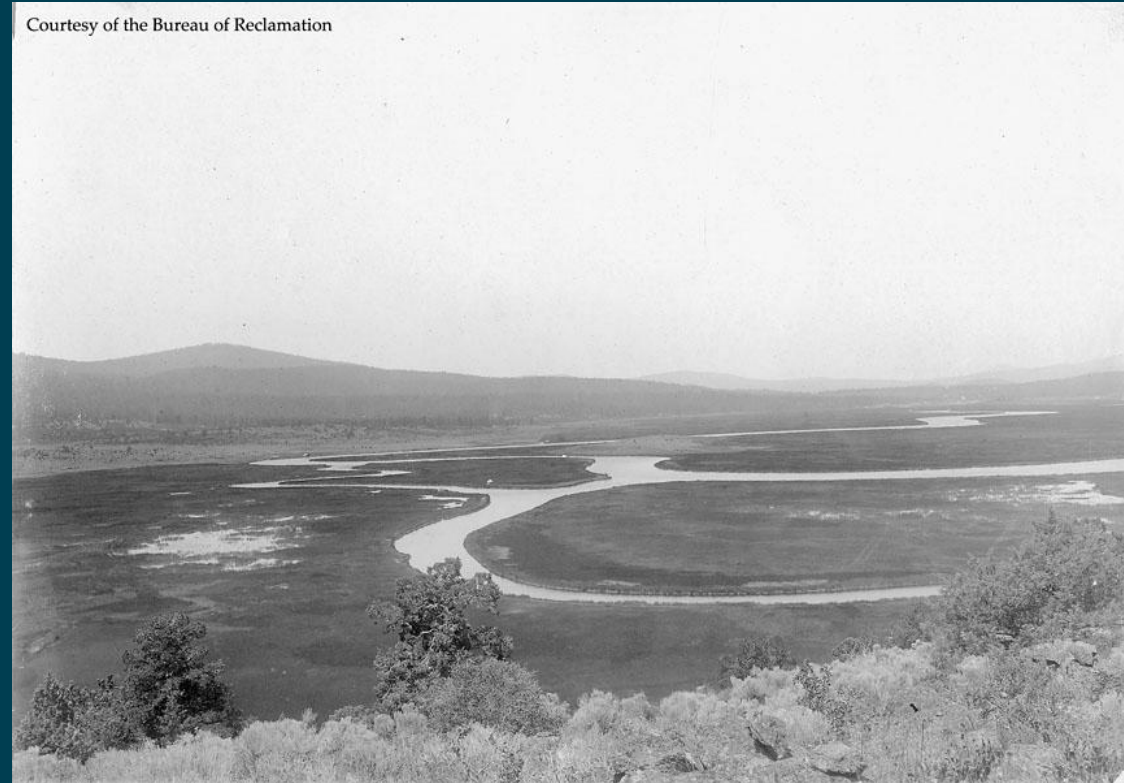
Modeling exchange flows between the
Klamath River and pre-development
Lower Klamath Lake

CWEMF

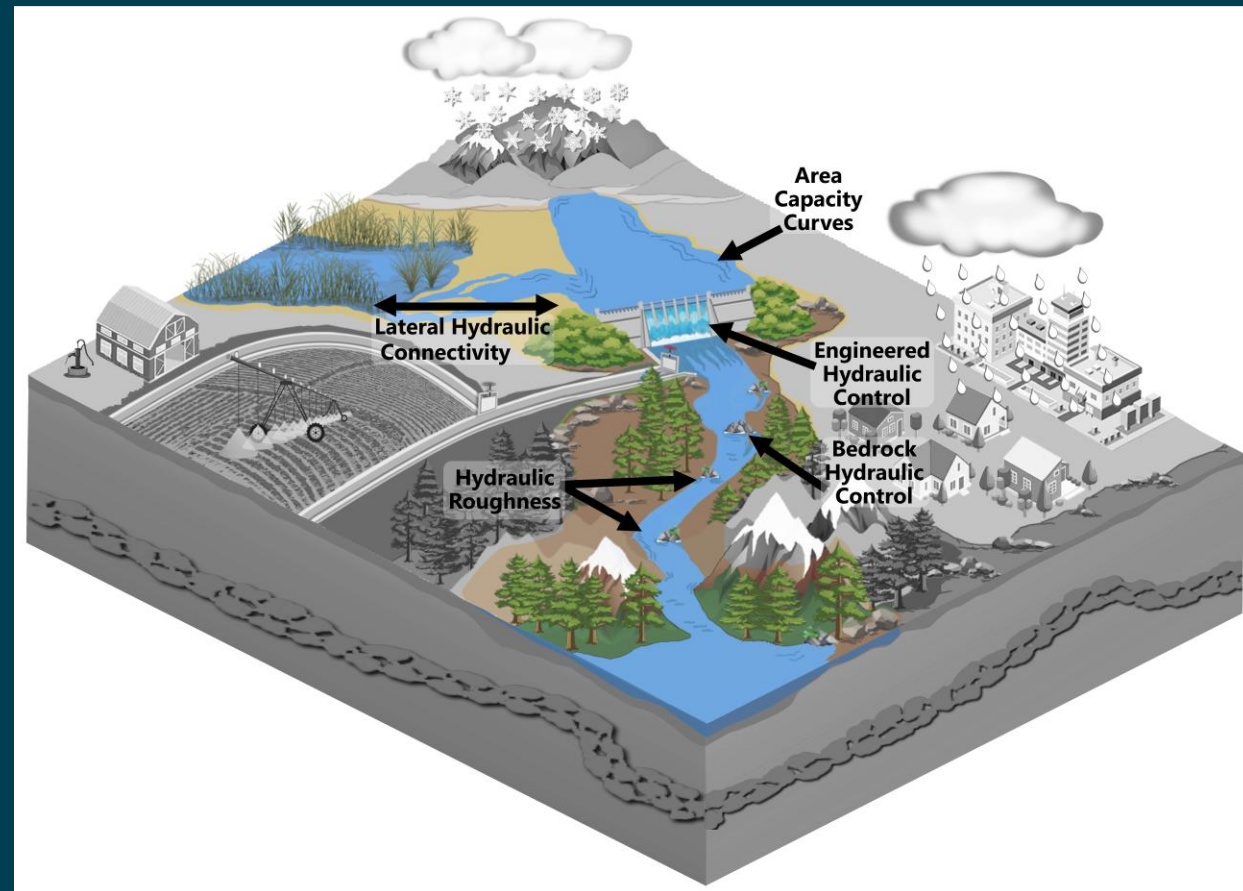
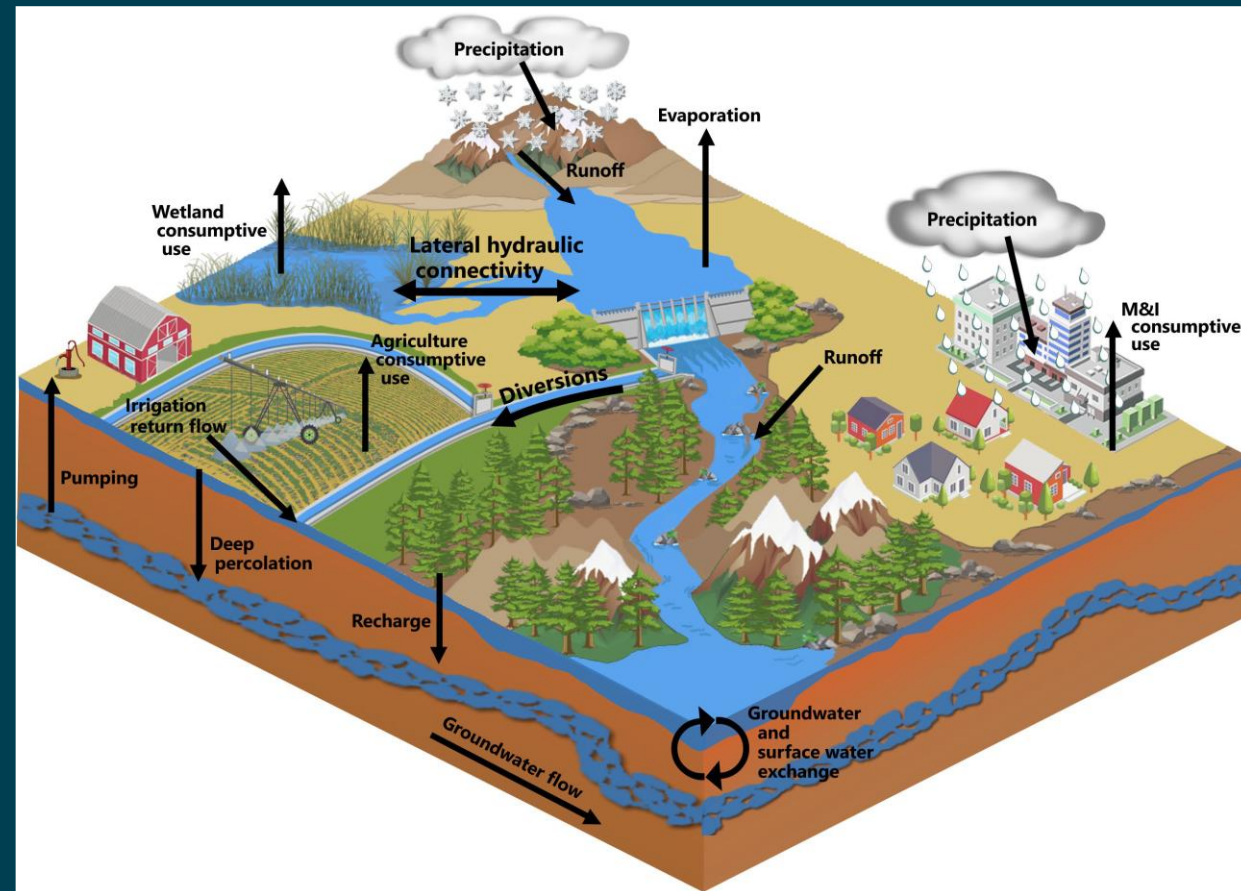
April 2026

Presented by: Colin Byrne, PhD

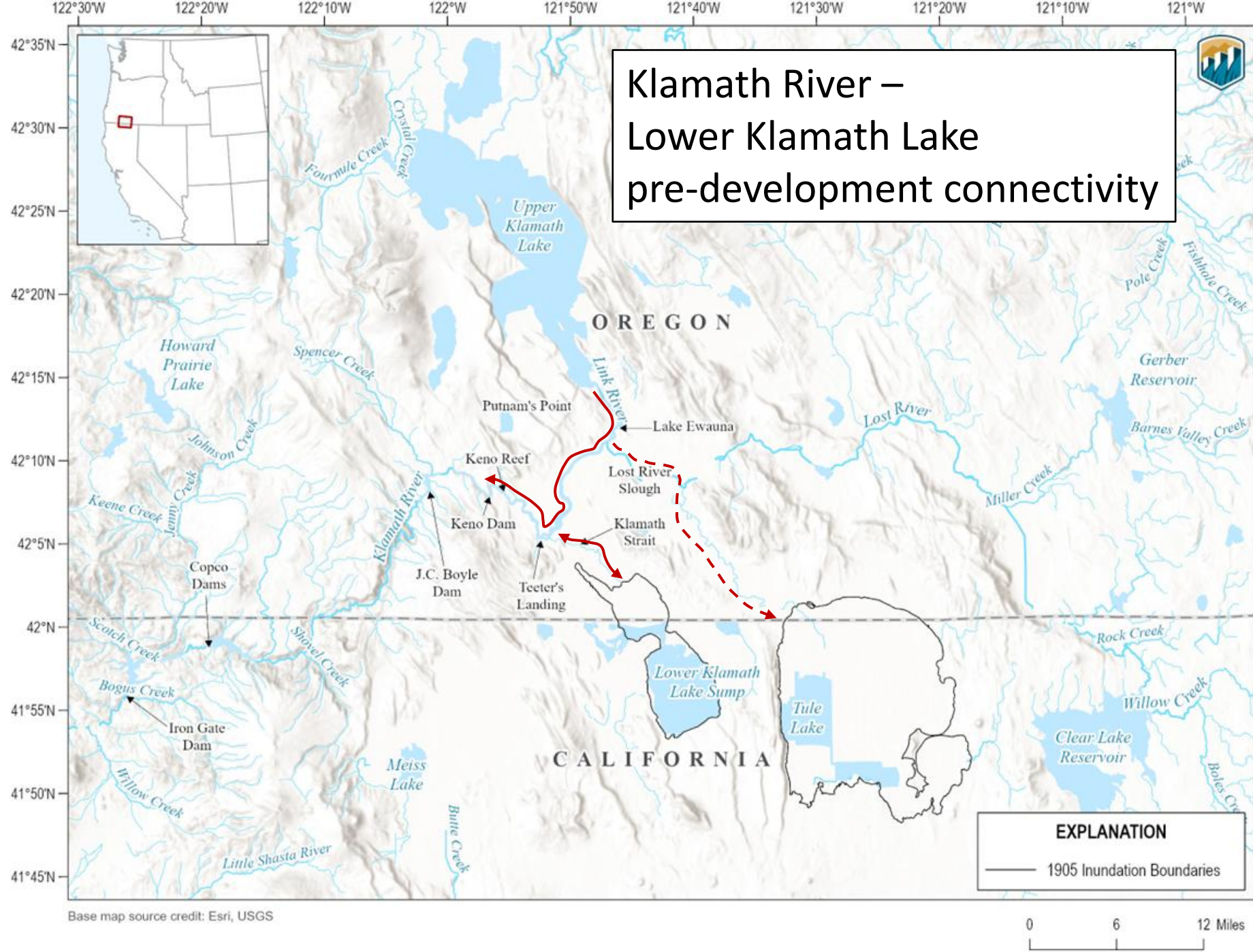
Courtesy of the Bureau of Reclamation



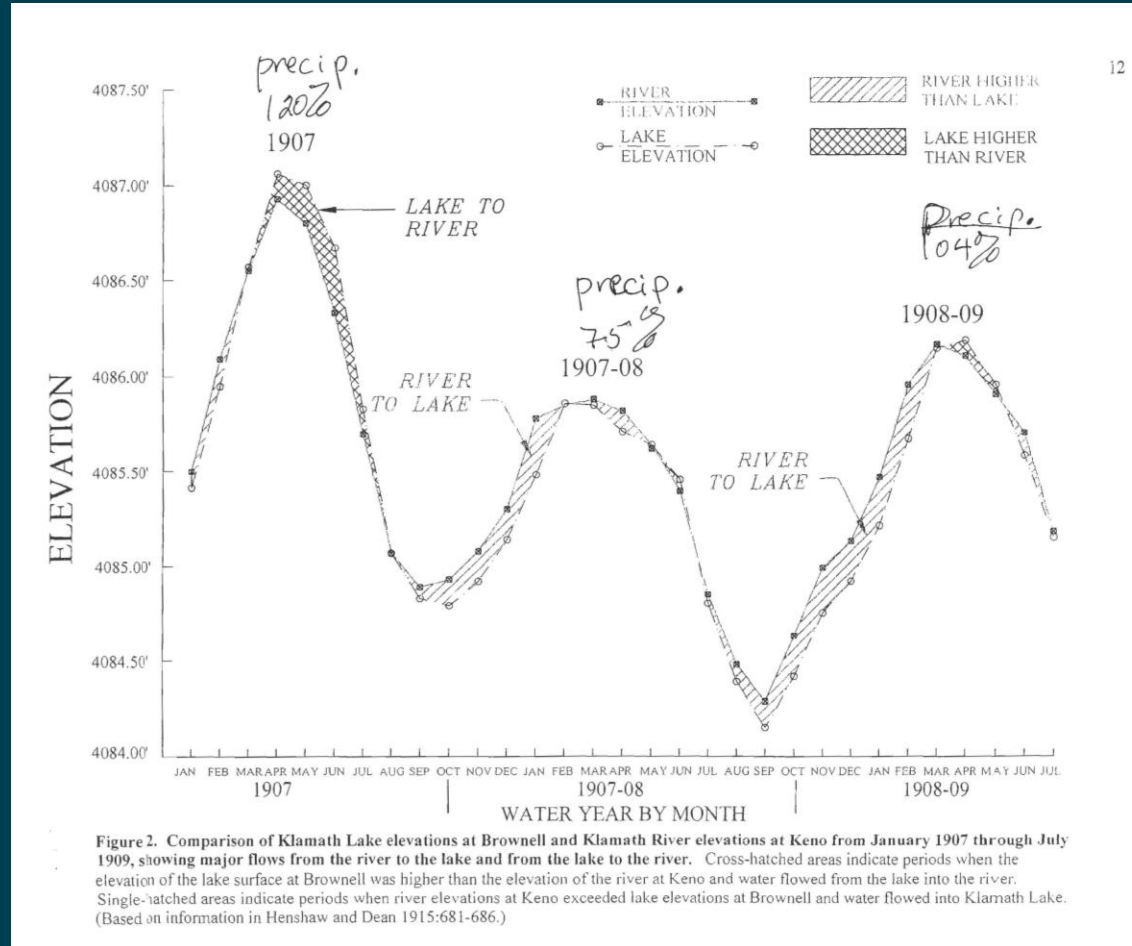
Hydraulics Component



Klamath River – Lower Klamath Lake pre-development connectivity



Conceptual hydraulic relationship between Klamath River and Lower Klamath Lake



- Generally, it is thought that the river contributed to the lake during the rising limb of the hydrograph
- After flows peaked, the lake could drain to the river (in wet years)



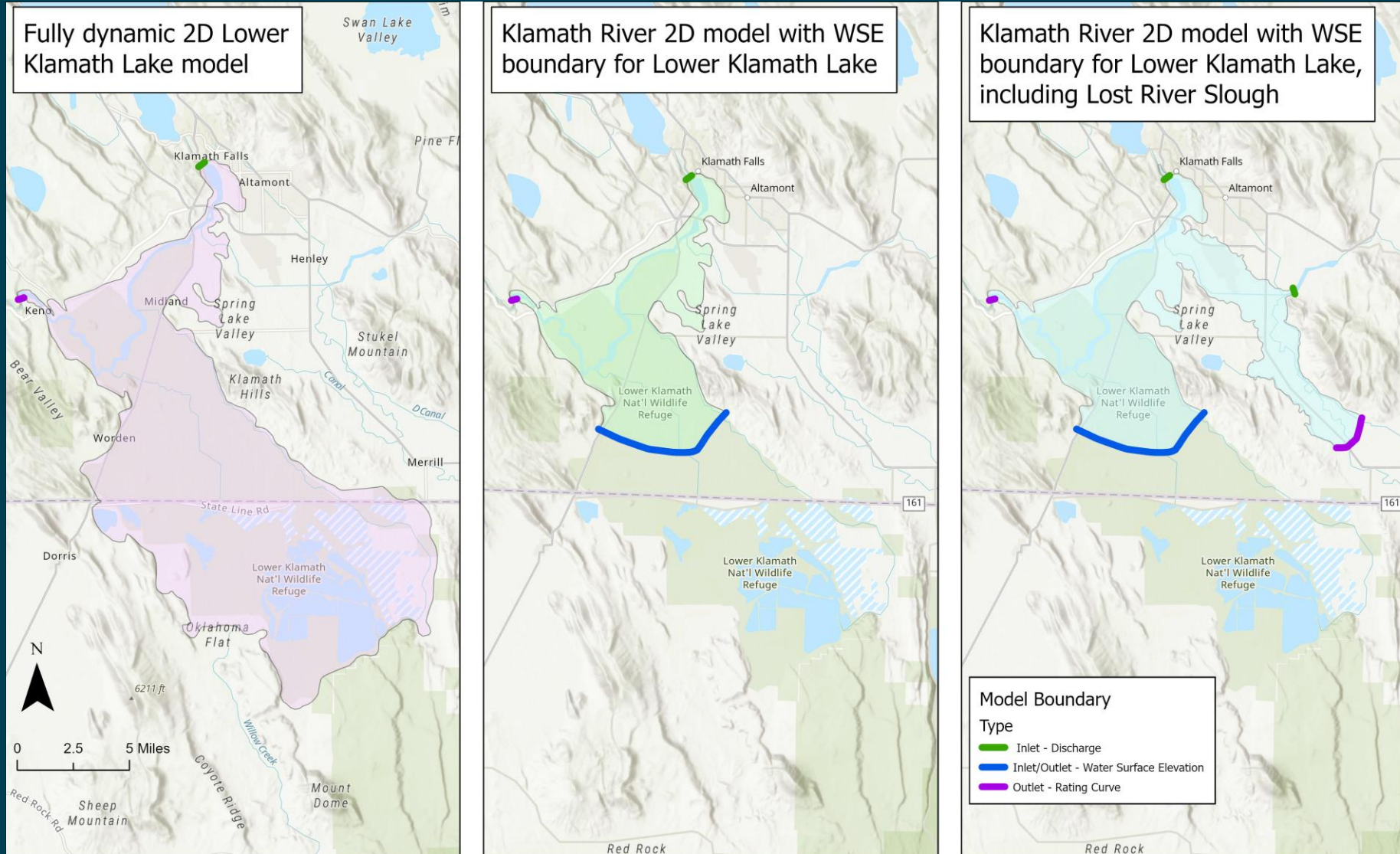
Klamath River to Lost River/Tule Lake



- Connected through Lost River Slough (LRS)
- For model performance assessment, LRS losses not included in the results shown here as a levee was constructed across the slough connection in 1890
- Lost River Slough is included in final flow estimates

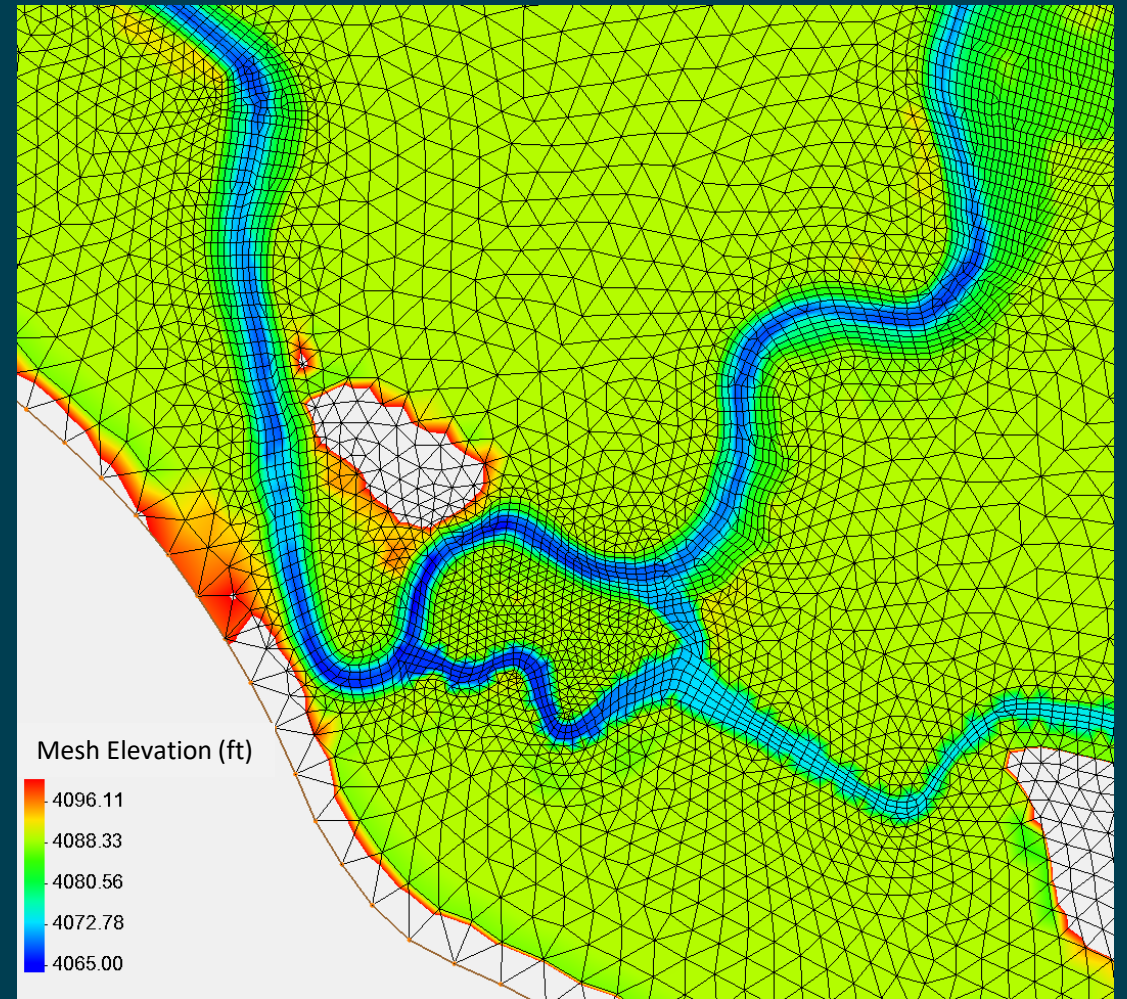


Three models were developed for different purposes: 1) Calibration, 2) Proof-of-Concept, 3) Final Flow Exchange.



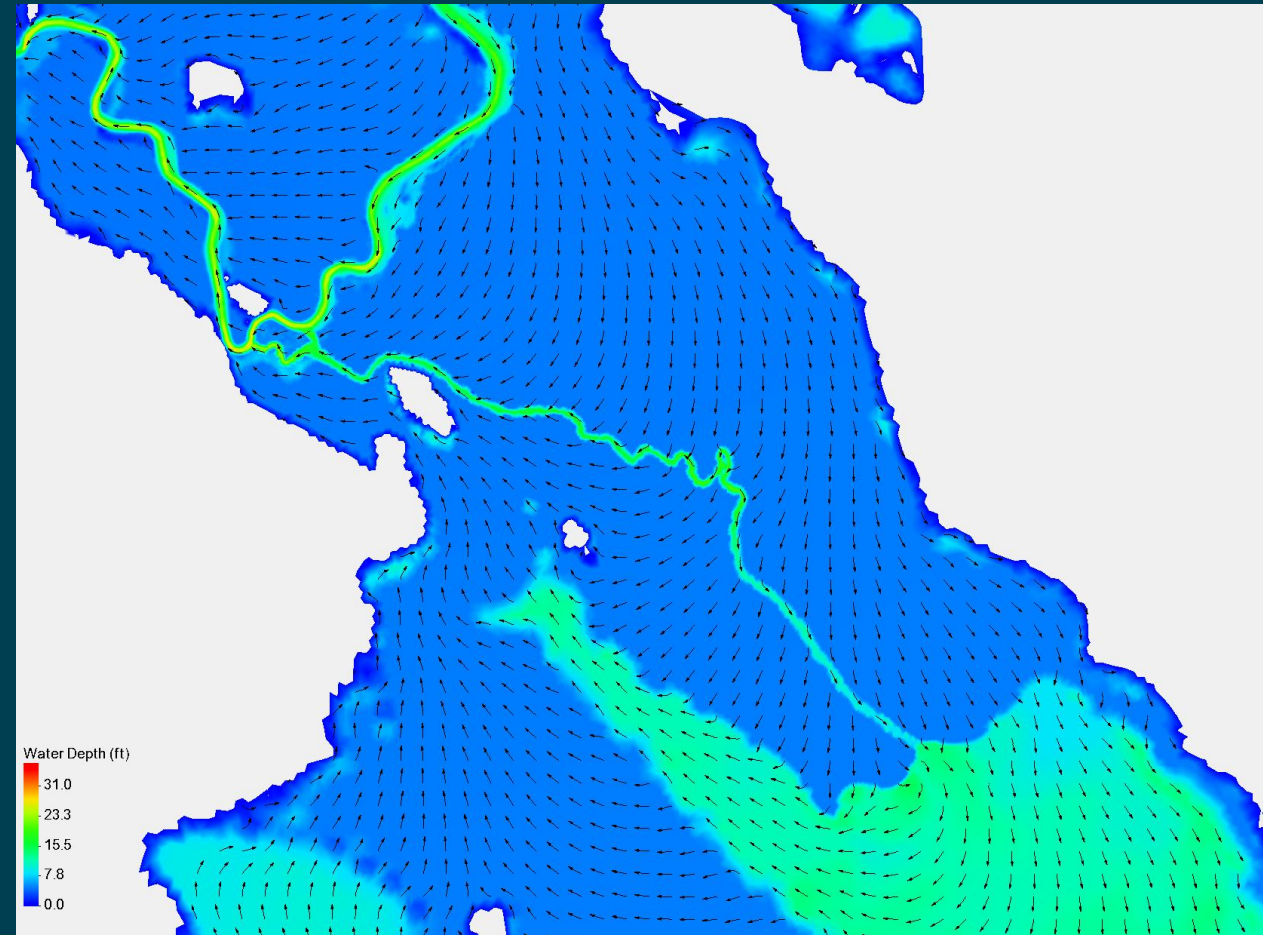
Hydraulic Modeling Components

- Sedimentation and River Hydraulics Two-Dimensional (SRH-2D) model
- Selected due to its robust computational capabilities
- Well documented use in all sorts of modeling environments
- Ability to model depth-variable vegetation roughness

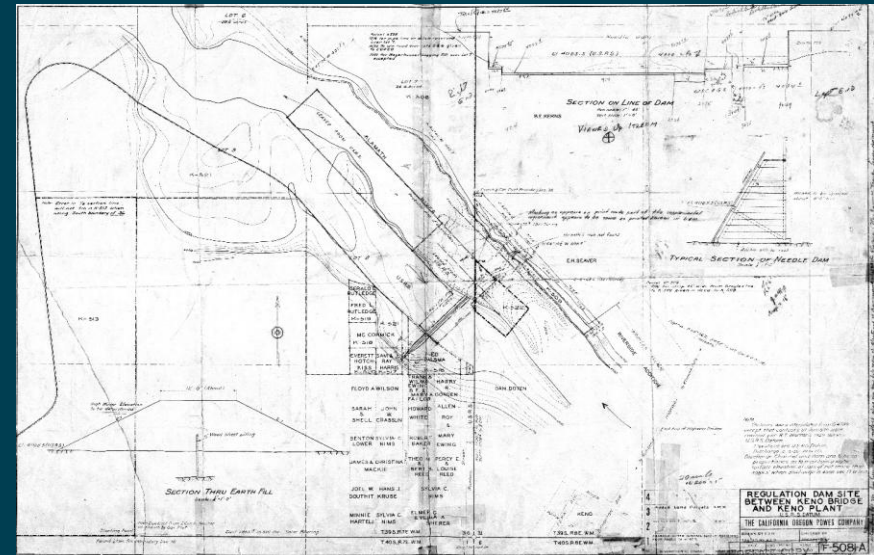
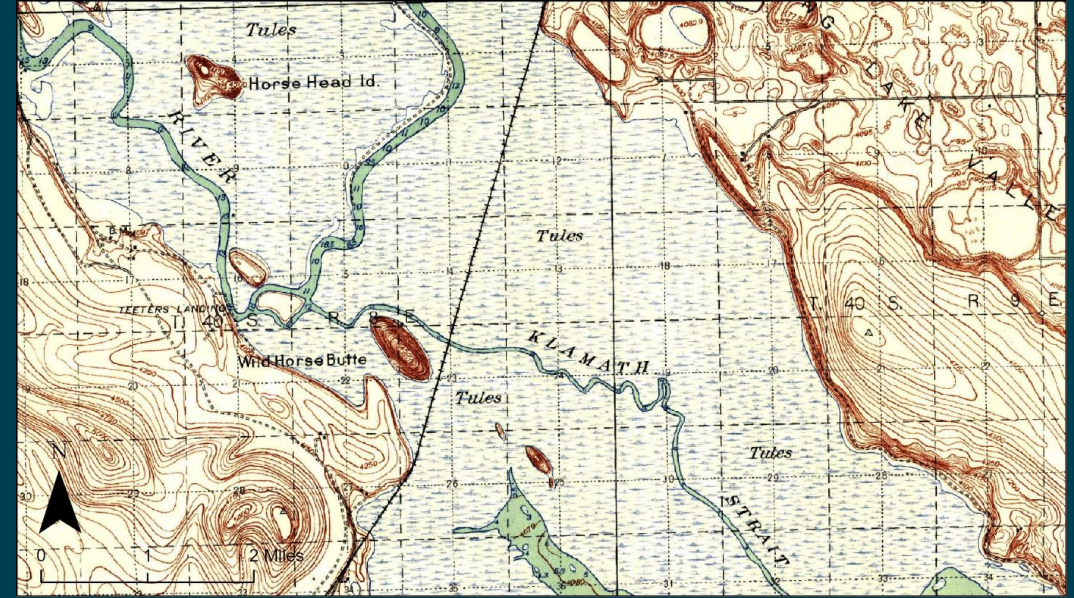
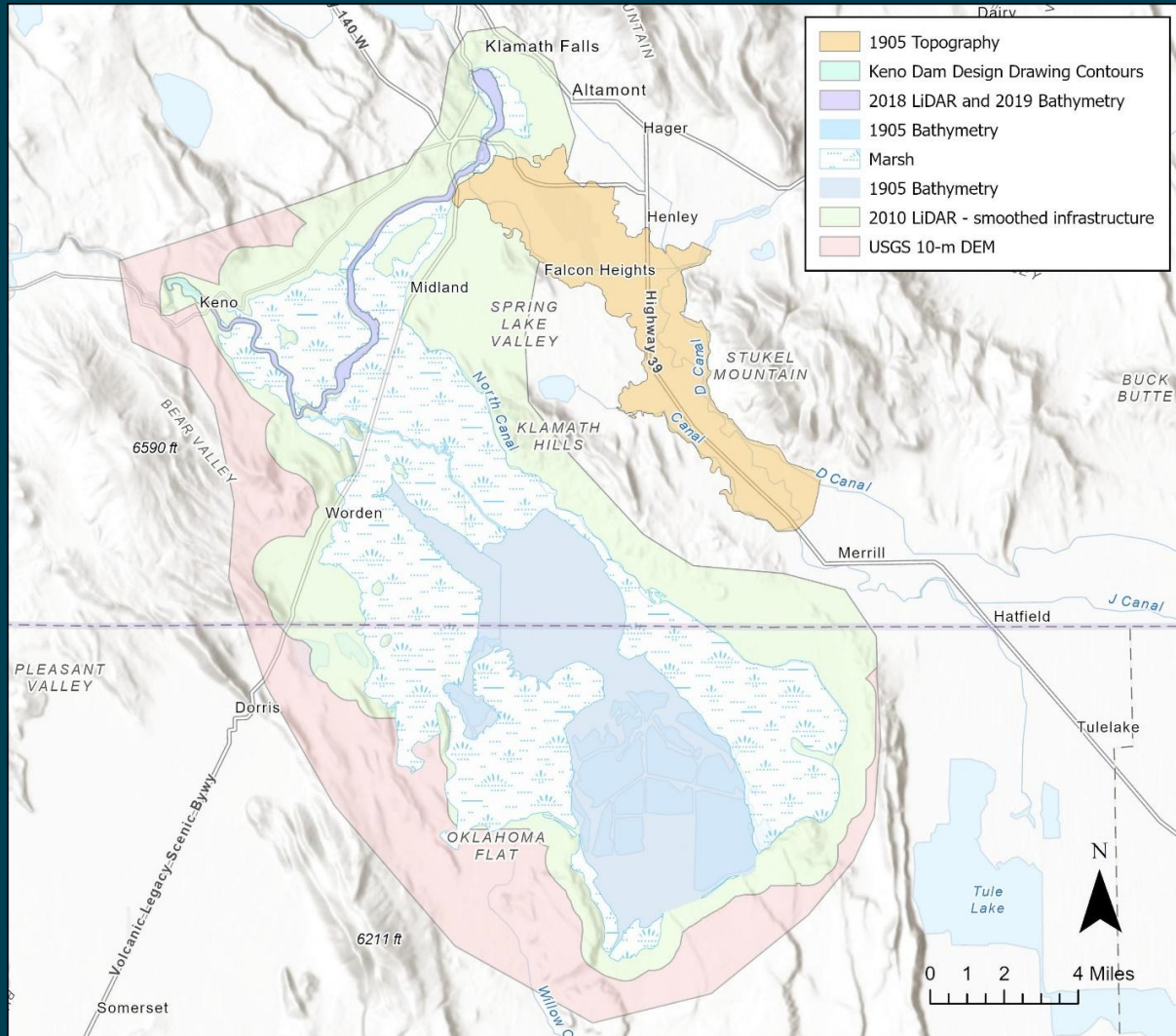


Modeling Methodology

- Develop terrain
 - 1905 survey, reef contours, 2018 bathymetry, 2018 bathymetric lidar, 2010 lidar
- Roughness parameterization
 - Tule marshes and bedrock reefs have most influence on flow
- Assign boundary conditions
 - Upstream flows from Henshaw & Dean from 1904-1908
 - Steady flows that are thought to be reasonable for pre-development conditions



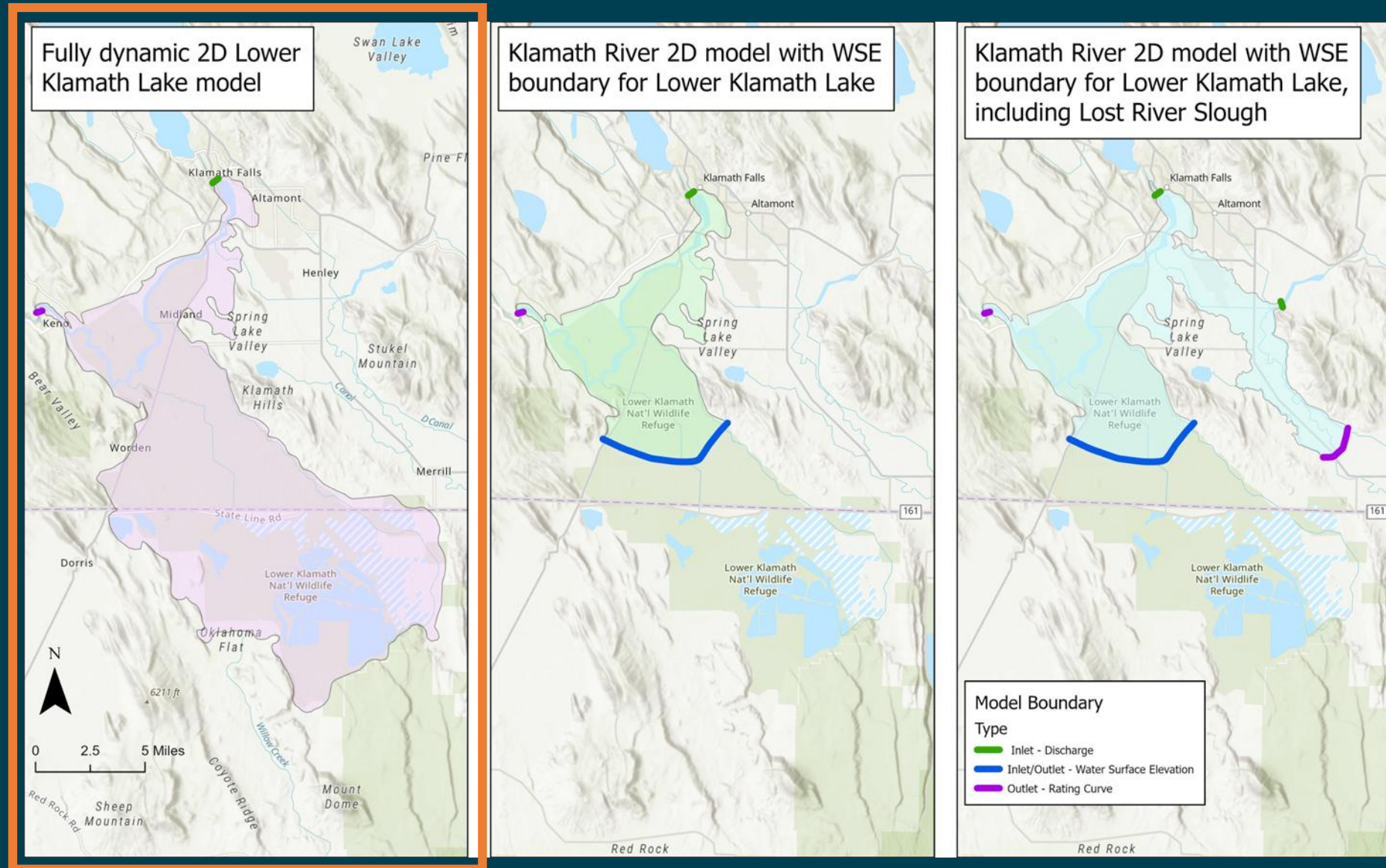
Model topography was a combination of data sources including the 1905 contours, reef contours, lidar, and calibrated tulle elevations



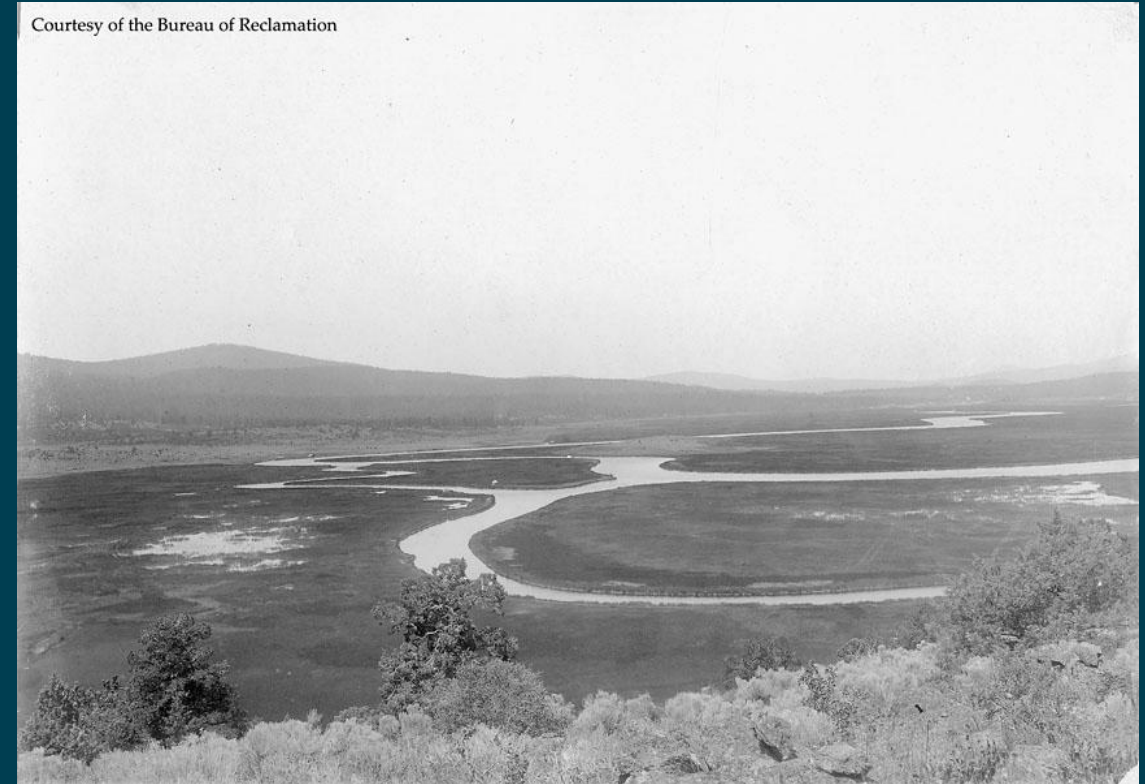
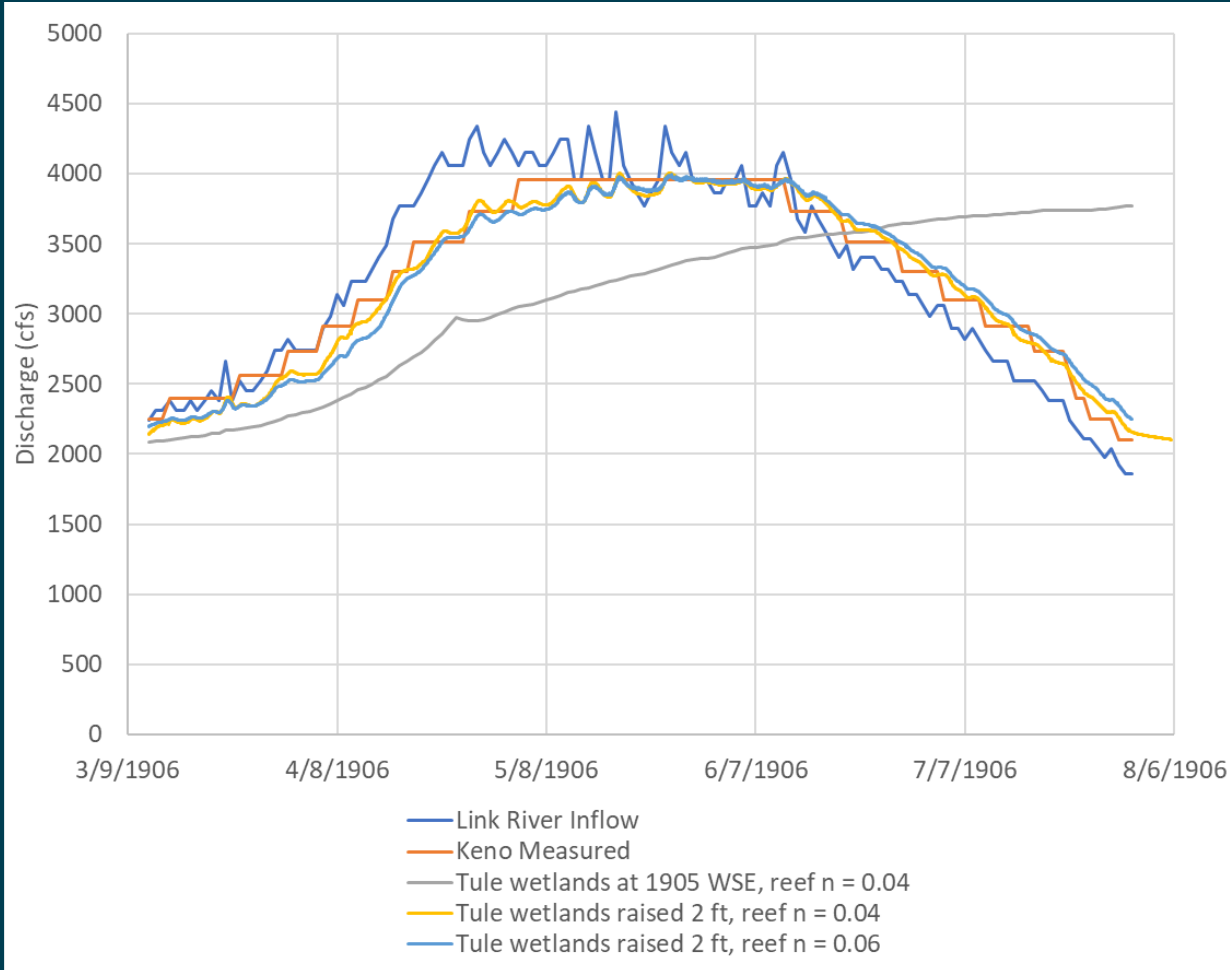
The 1905 map provides no elevations within the tule wetland areas. The modeled tule wetland elevation was calibrated to 1906 flows to best approximate timing of flow to Keno, OR.



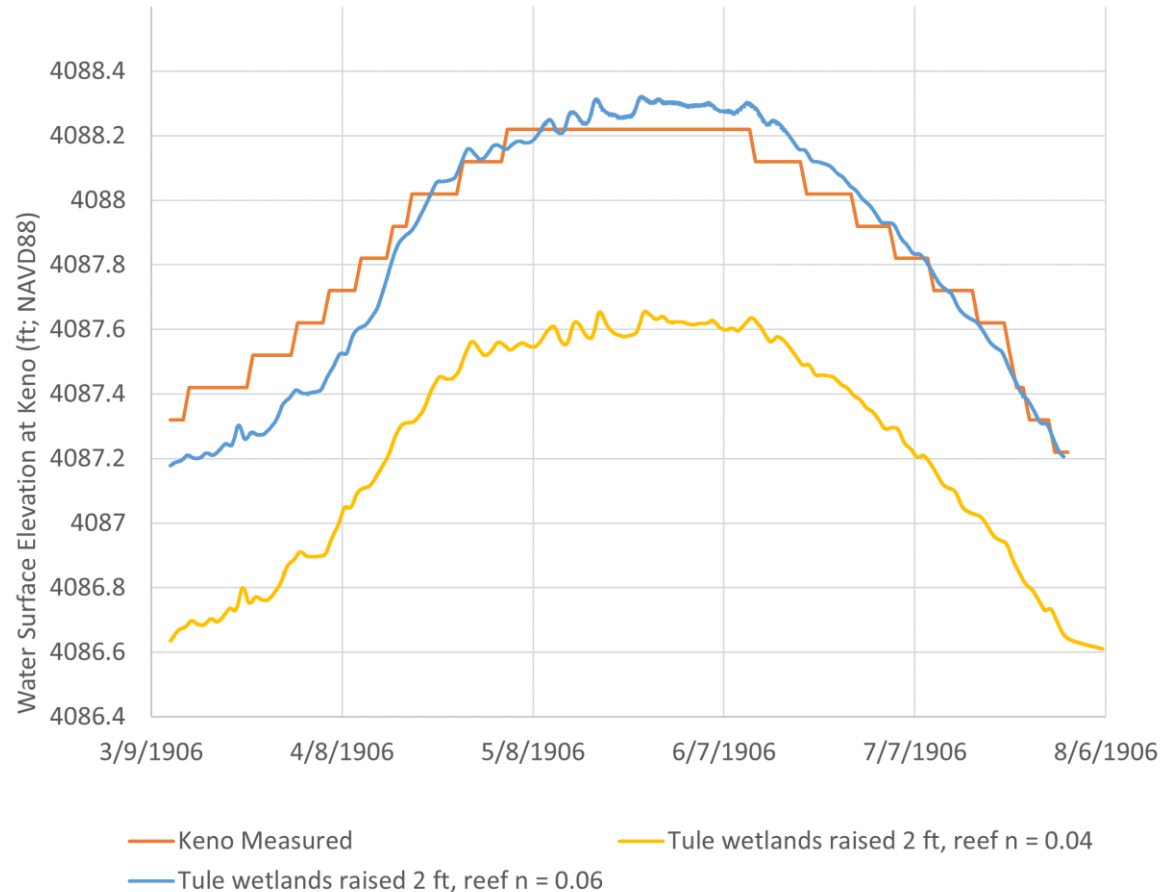
Calibration



The 1905 map provides no elevations within the tule wetland areas. The modeled tule wetland elevation was calibrated to 1906 flows to best approximate timing of flow to Keno, OR.

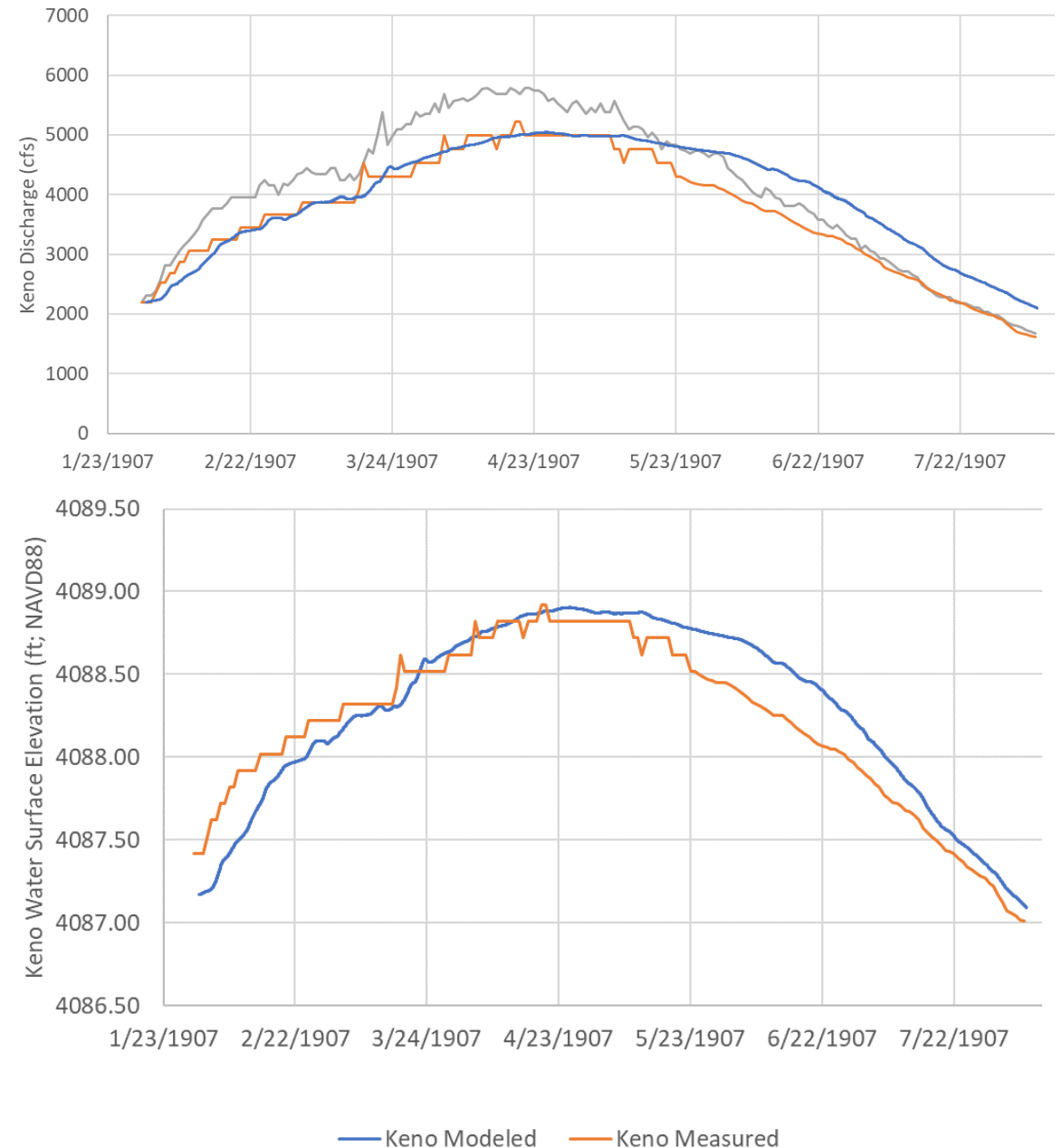


The water surface elevation at Keno Reef was documented to be extremely important to Lower Klamath Lake water surface elevations, so roughness at Keno Reef was used to calibrate.

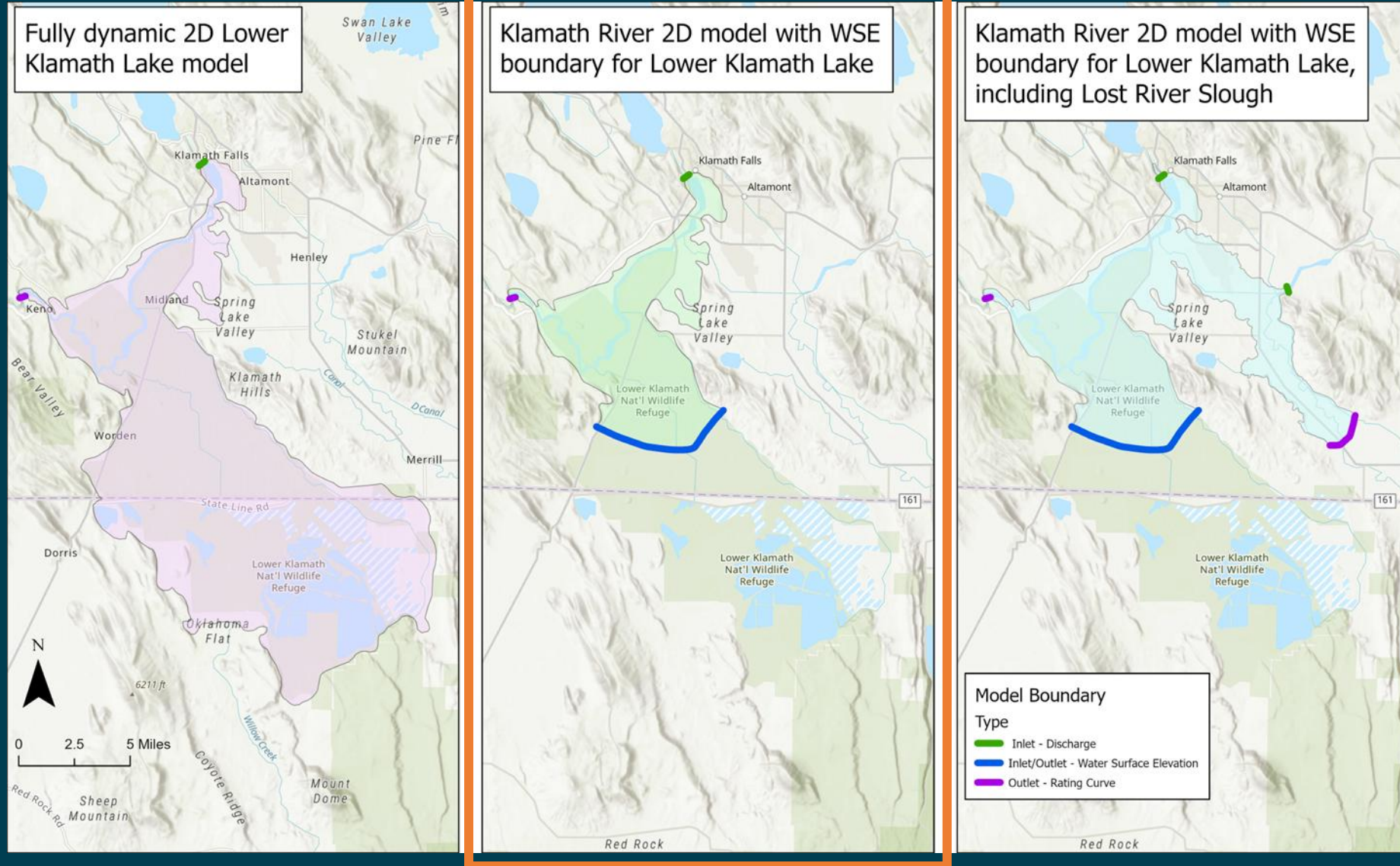


Model Verification

- Model calibrated to 1906 and performance was assessed with 1907 flows
 - 1906 and 1907 are best available datasets prior to construction of railroad levee between the Klamath River and Lower Klamath Lake
- Calibrated model performs well according to statistical assessments



Proof-of-Concept



Hydraulic Analysis of LKL Connection

Problem:

- We can't model 40-years of flows with a two-dimensional model like SRH-2D as computational requirements would be too high
- Since the lake doesn't drain/evaporate completely on an annual basis, hysteresis likely plays a role in the connection.



Hydraulic Analysis of LKL Connection

Solution:

- Run steady two-dimensional hydraulic models for certain lake conditions and river flows
- Create a simplified flow transfer relationship between the river and lake (i.e. a look-up matrix)
- Apply the transfer relationship to the long-term time-series
- Termed a *quasi-unsteady approach*



Klamath River – Lower Klamath Lake Flux

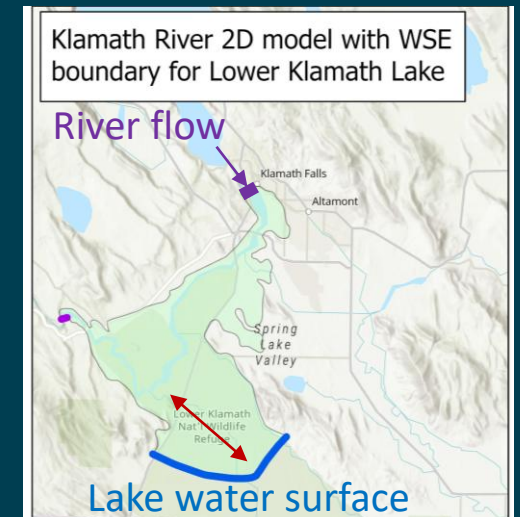
Example of Klamath River Flow – Lower Klamath Lake WSE matrix

Each box is a model run with different boundary conditions (i.e. different upstream flow and LKL water surface elevations)

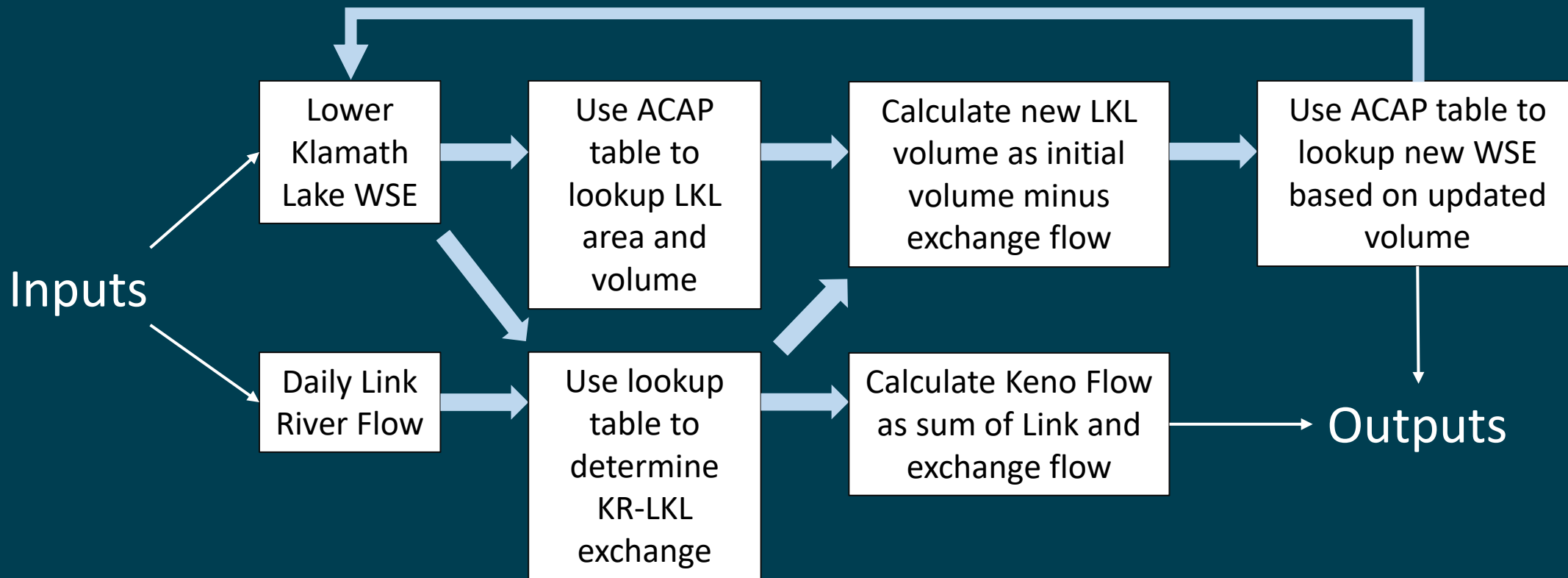
Klamath River Flow (ft ³ /s)	LKL Water Surface Elevations				
	4080	4080.5	...	4086.5	4087
500	0	0	...	1600	2000
1000	-100	-90	...	1500	1800
...	...	...	...	...	...
7500	-1800	-1500	...	0	20
8000	-2000	-1750	...	-20	0

Flow (cfs) contributed to the Klamath River

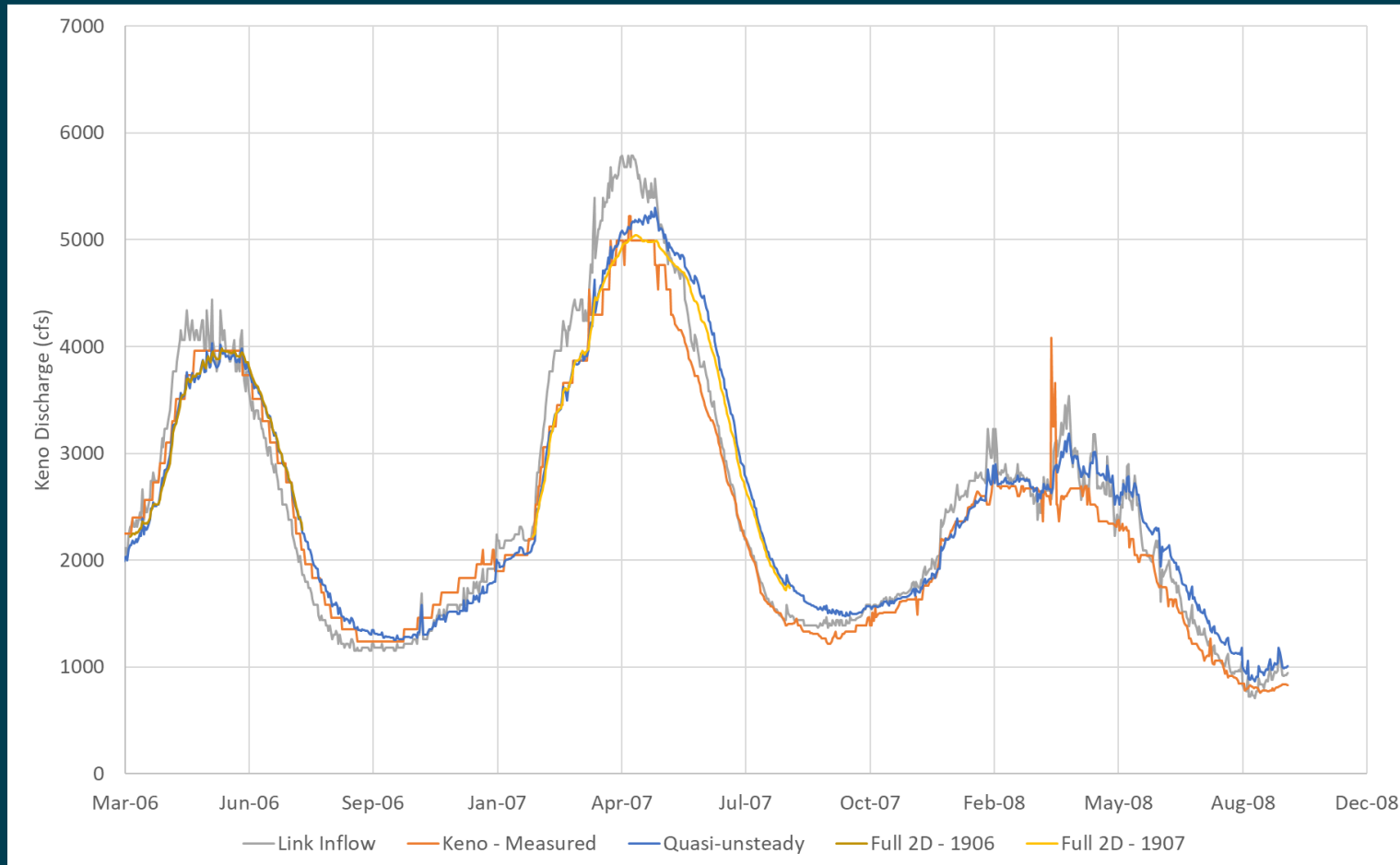
- Negative – flow from river to LKL
- Positive – flow from LKL to river



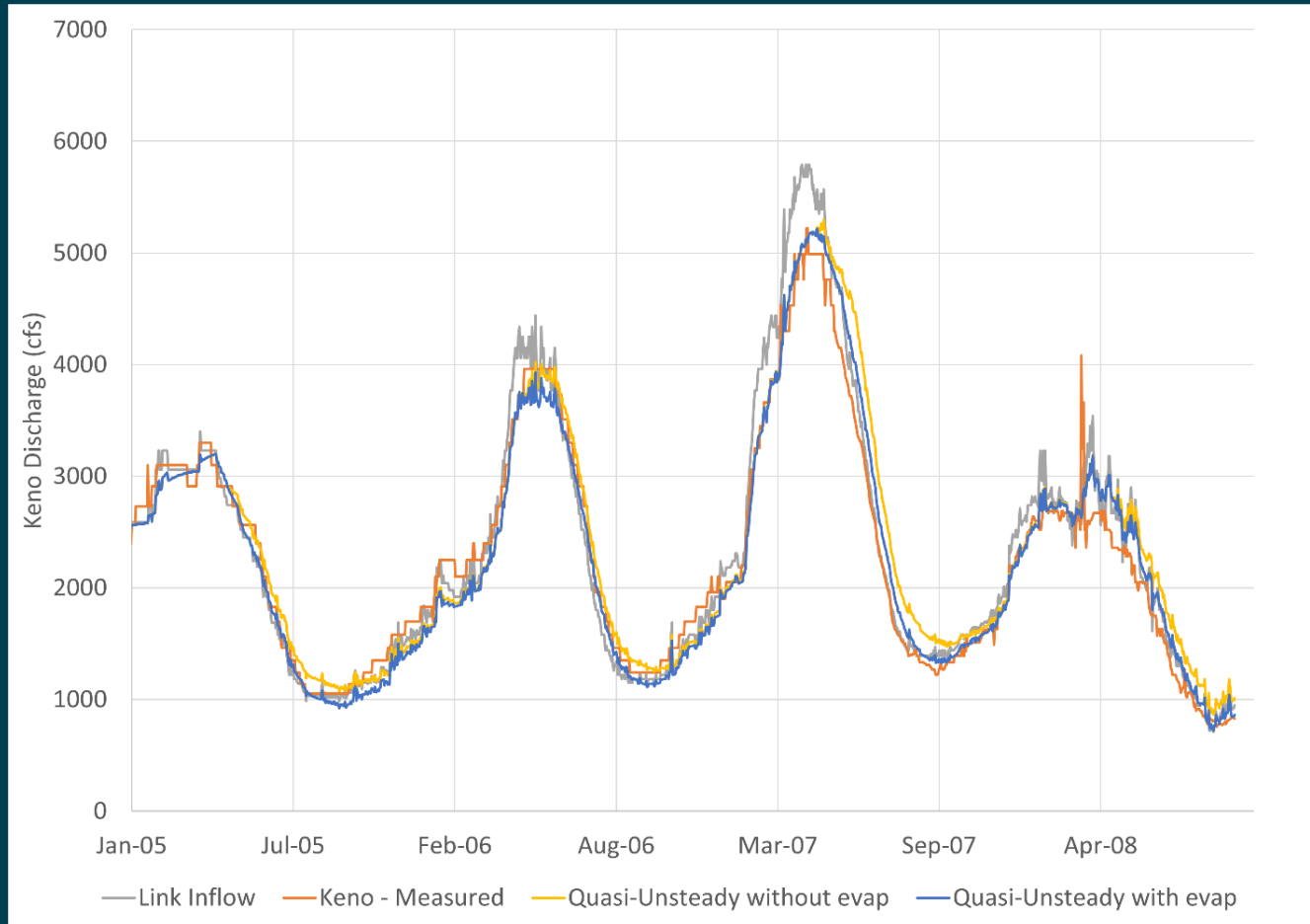
Workflow of Quasi-Unsteady Code



Quasi-unsteady approach performs similarly to fully 2D unsteady model, both tend to overpredict growing season flows



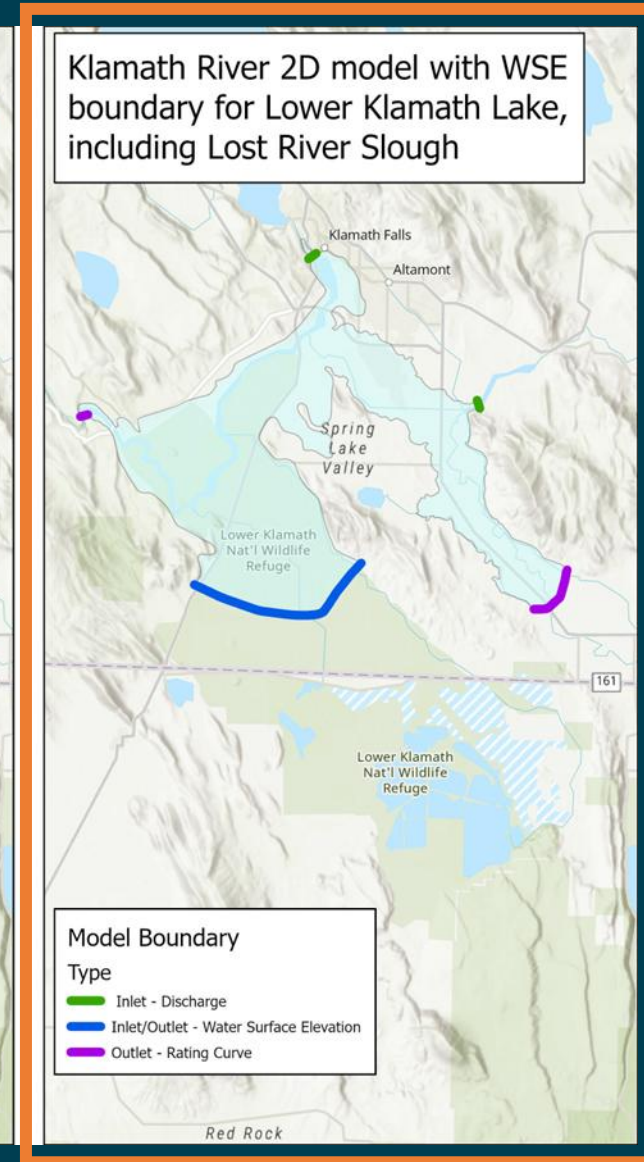
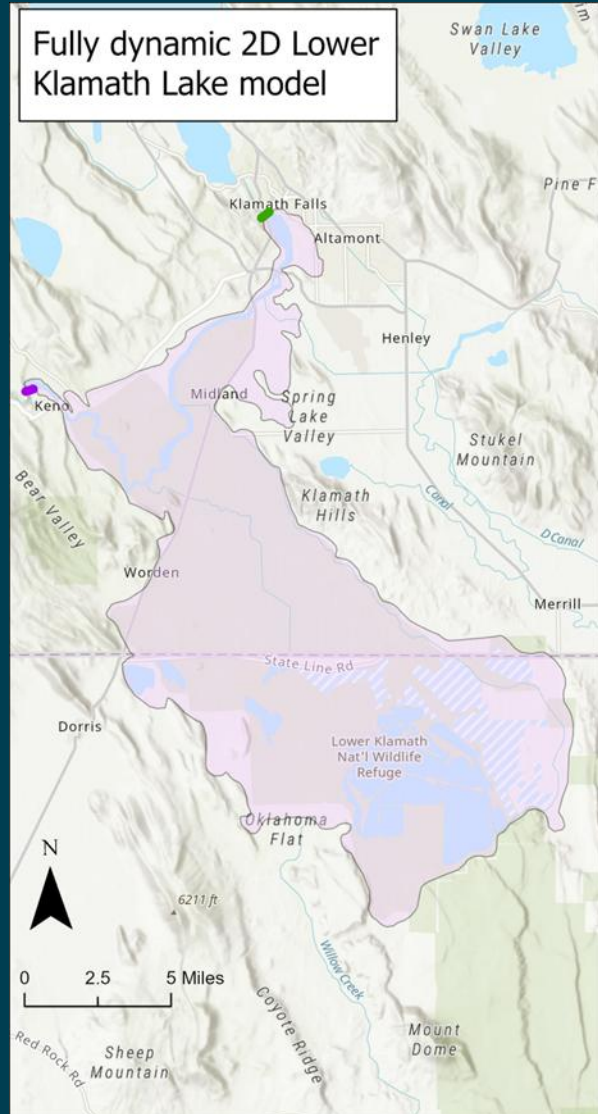
Quasi-unsteady approach gives us an opportunity to test performance with ET, which a fully 2D hydraulic model would not



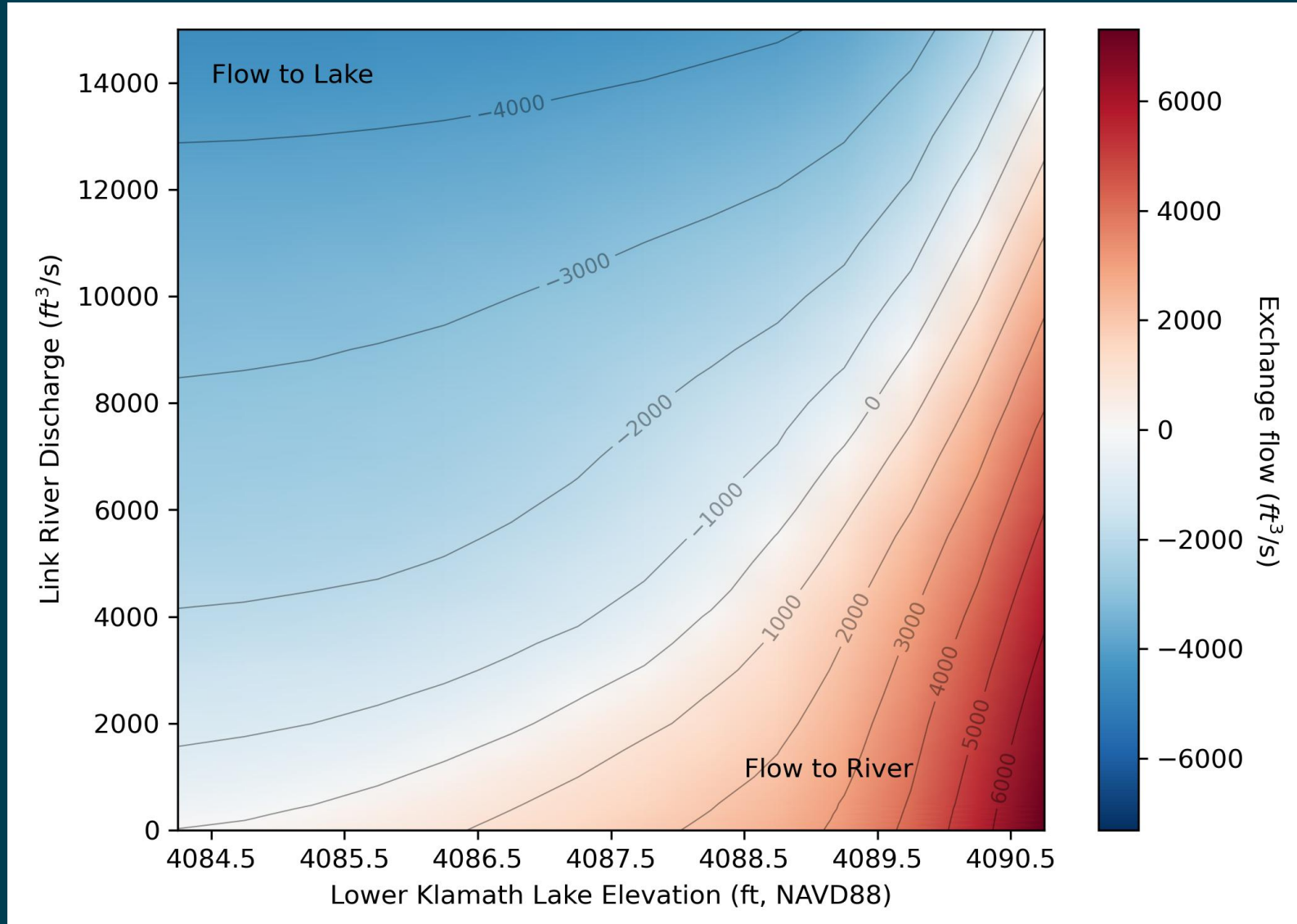
	1905-1908	
Statistic	No Evaporation	Open water evaporation
Mean flow difference (cfs)	-21.50	-15.03
Mean WSE difference (ft)	-0.16	-0.12
Percent bias	-3.66	-0.66
RMSE	266.9	204.7
Nash-Sutcliffe efficiency	0.93	0.96
Observed Standard Deviation	1,008.51	1,008.51
RSR	0.26	0.20



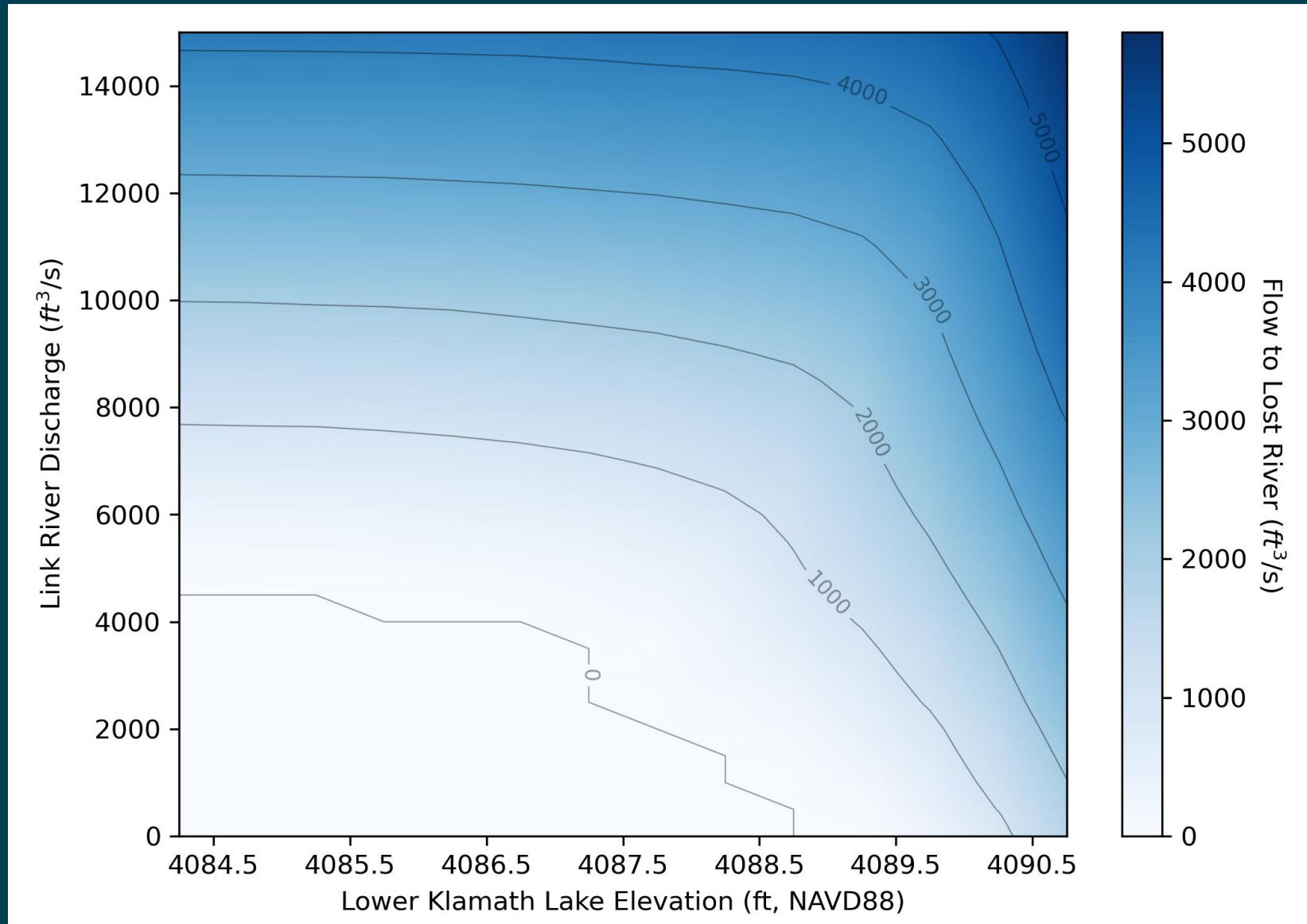
Final Flow Exchange



Klamath River – Lower Klamath Lake Exchange



Klamath River – Lost River Slough Exchange



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<https://data.usbr.gov/catalog/8528>



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