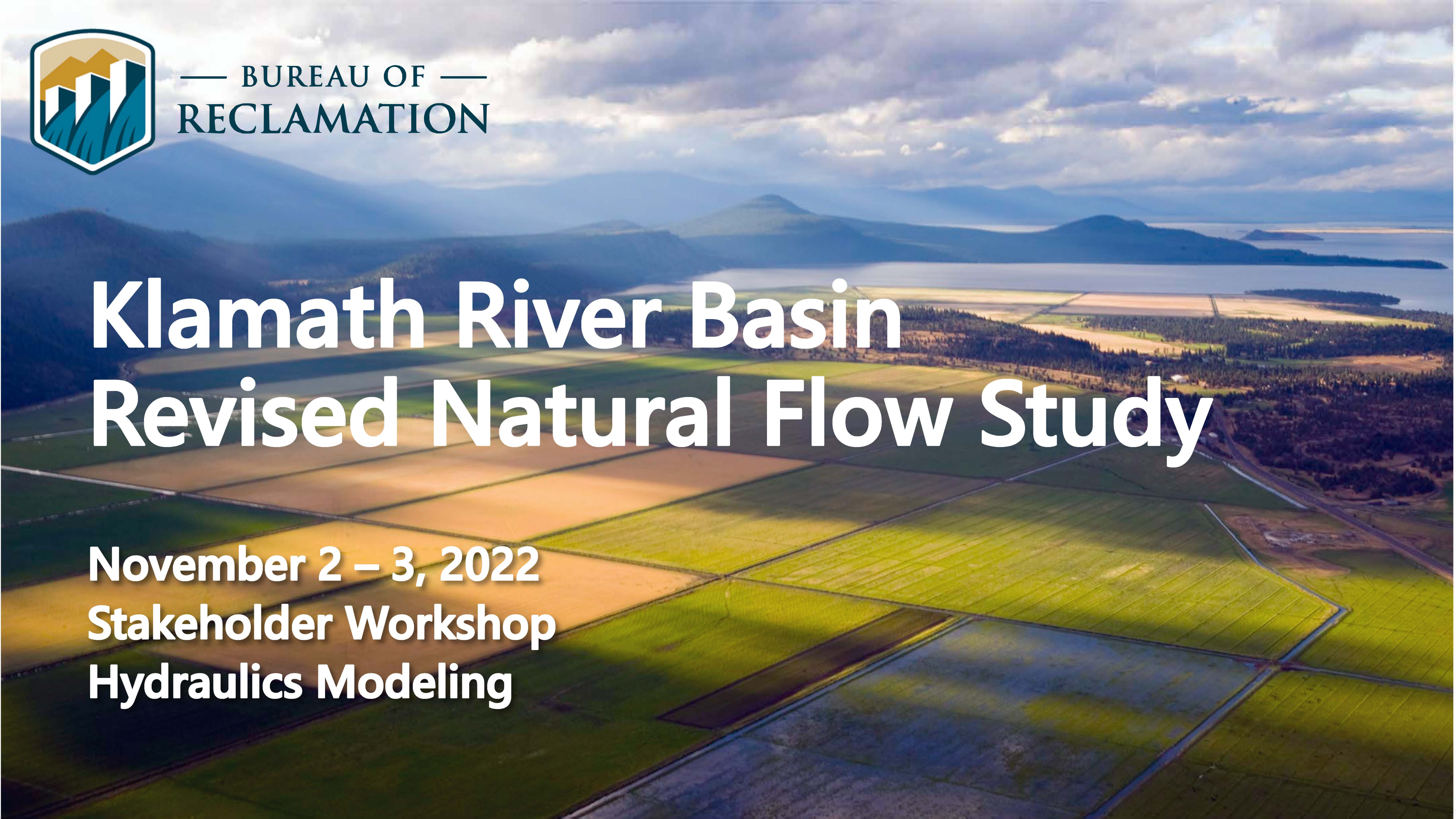


BUREAU OF RECLAMATION

Klamath River Basin Revised Natural Flow Study

November 2 – 3, 2022

Stakeholder Workshop

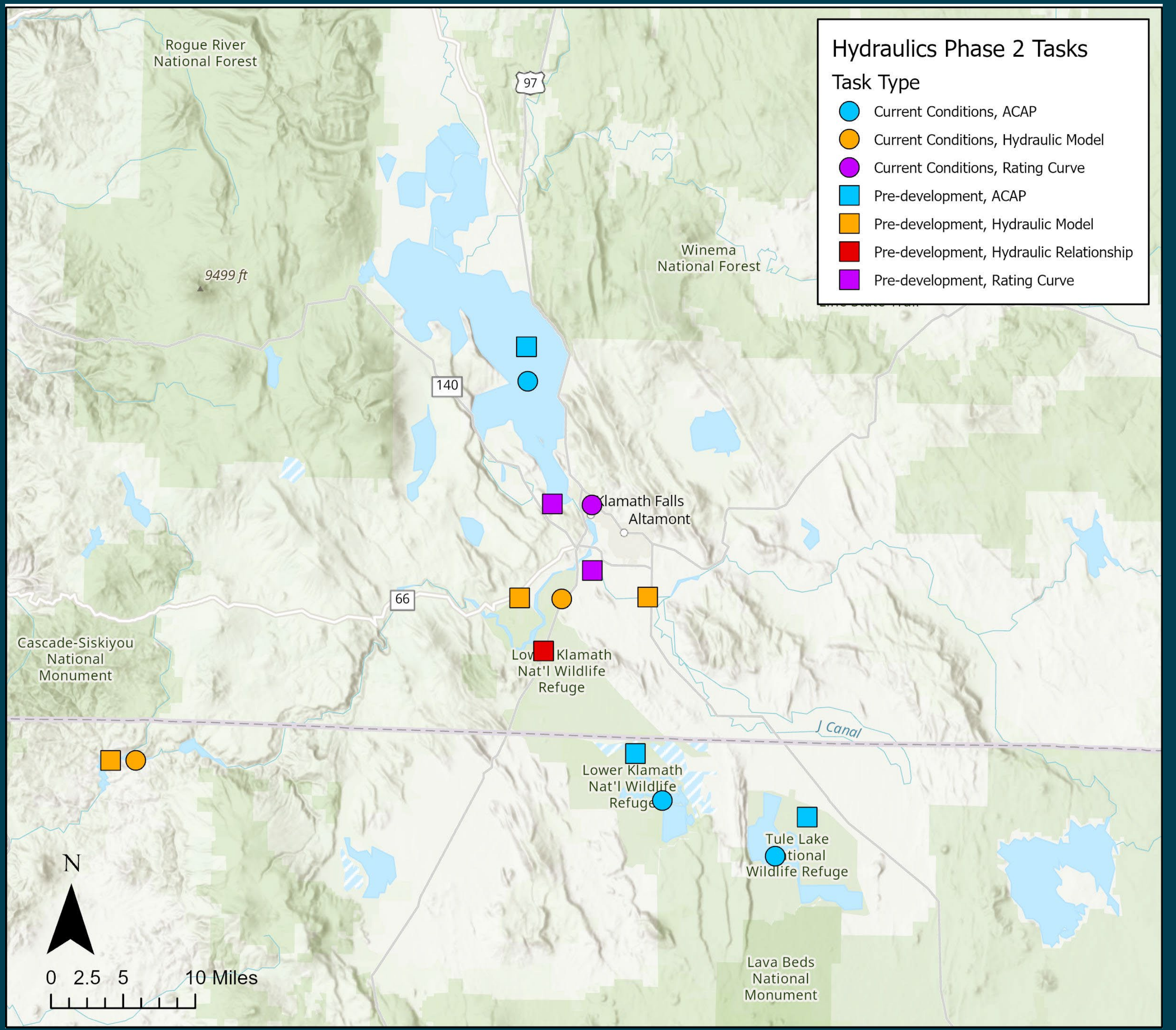
Hydraulics Modeling

Outline

- Model Purpose
- Input Data
- Model Selection
- Methodology
- Natural Flow Representation
- Sensitivity & Uncertainty Analysis

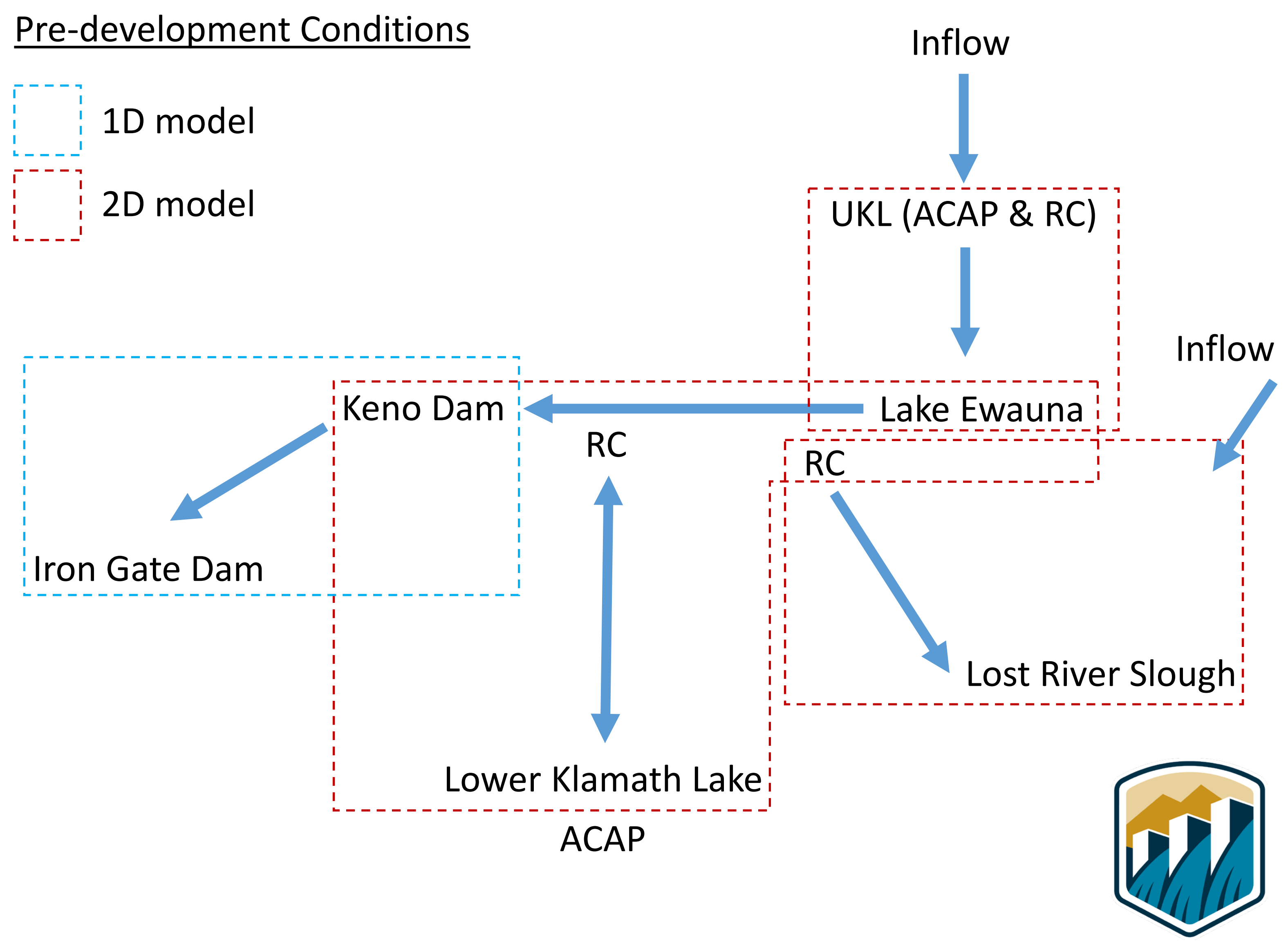
Hydraulics Modeling

- The purpose of the hydraulics portion of the natural flows study is to investigate the surficial movement and storage of water in complex locations of the Klamath River Basin
- This includes locations controlled by bedrock reefs and relatively flat areas of the basin



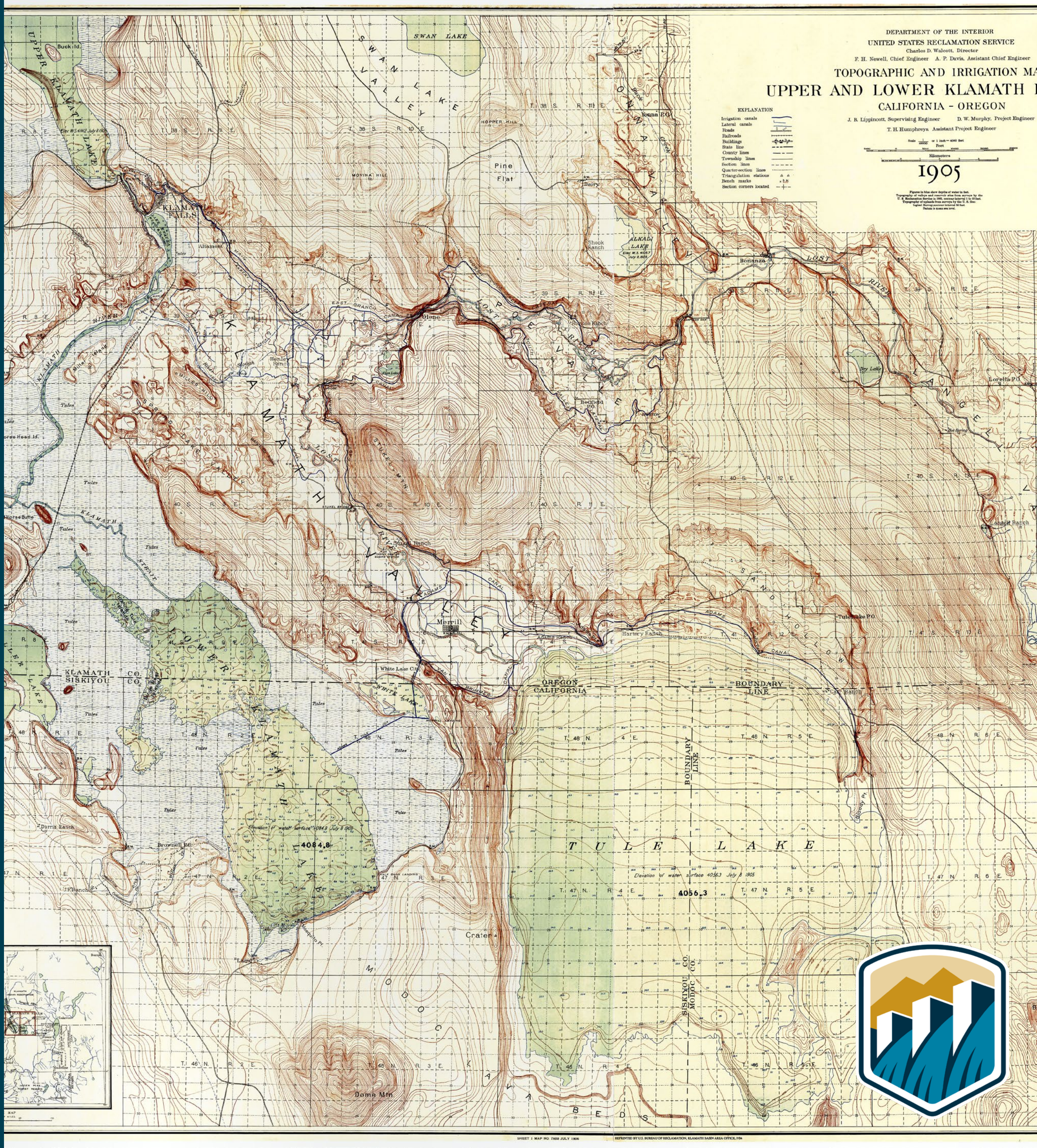
Model Extent

- Several models and area-capacity relationships are being developed to understand how water moved under pre-development conditions



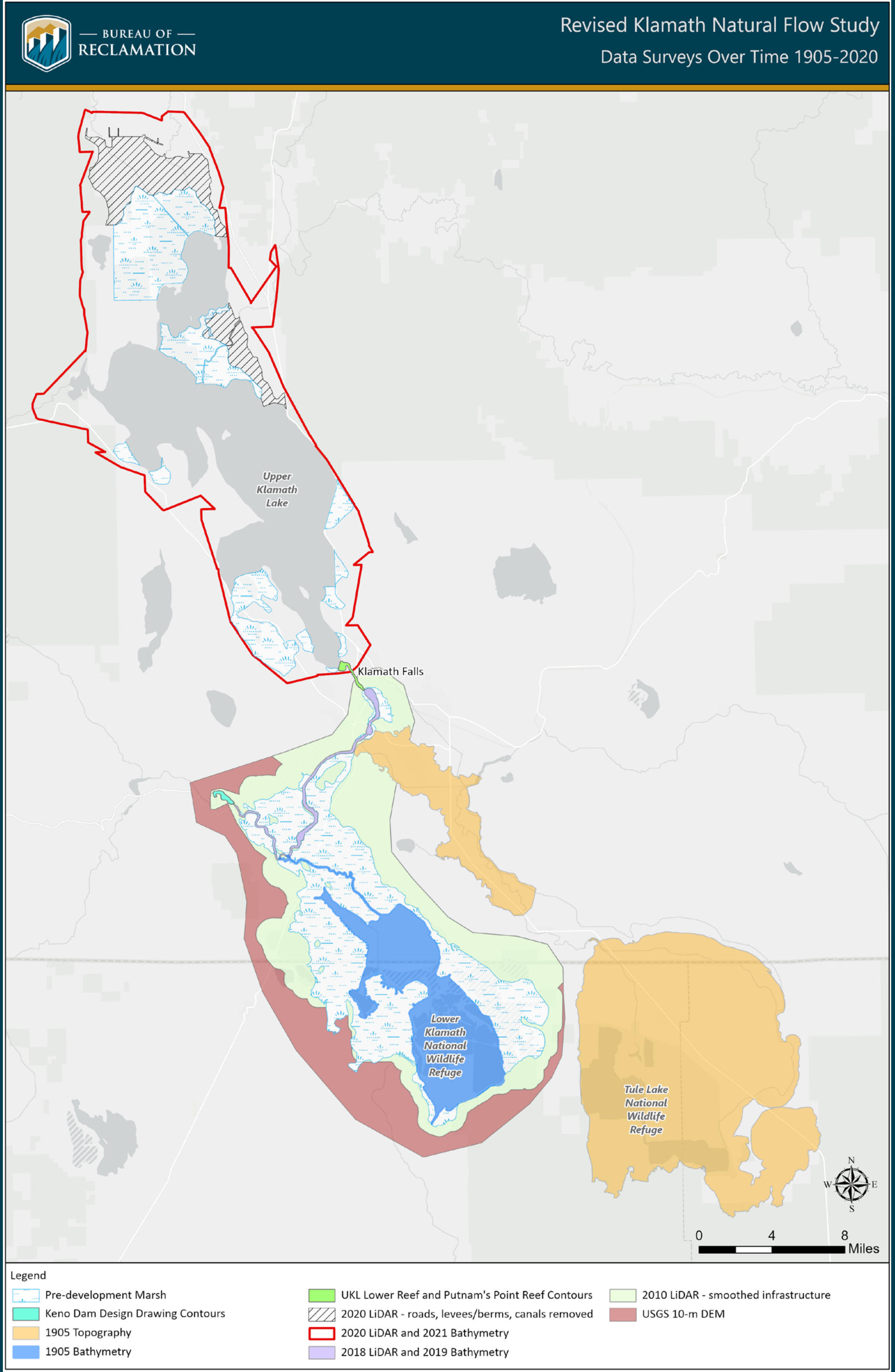
Input Data

- A variety of data sources are being used to create topographic surfaces for modeling and ACAPs. Key types of data include:
  - Historical contour maps
  - Light Detection and Ranging (LiDAR)
  - Bathymetric surveys

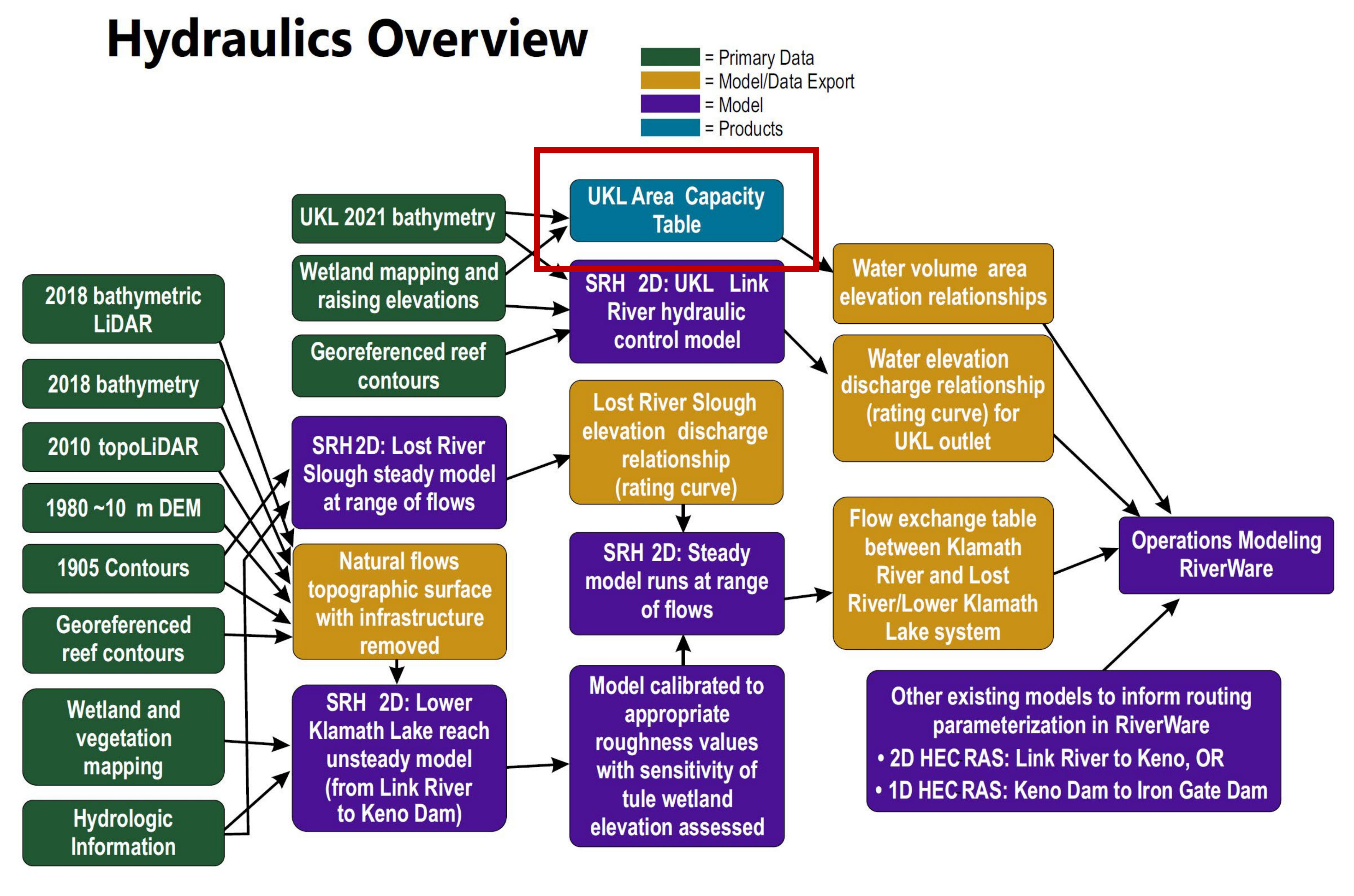


Input Data

- Specific data sources include:
  - 1905 contour map (topography and bathymetry)
  - 2021 UKL bathymetry
  - 2020 UKL LiDAR
  - 2018 Klamath River LiDAR
  - 2019 Klamath River Bathymetry
  - 2010 LiDAR
  - USGS 10-m DEM
  - Upper Klamath and Keno reefs reconstructed from contours and reports

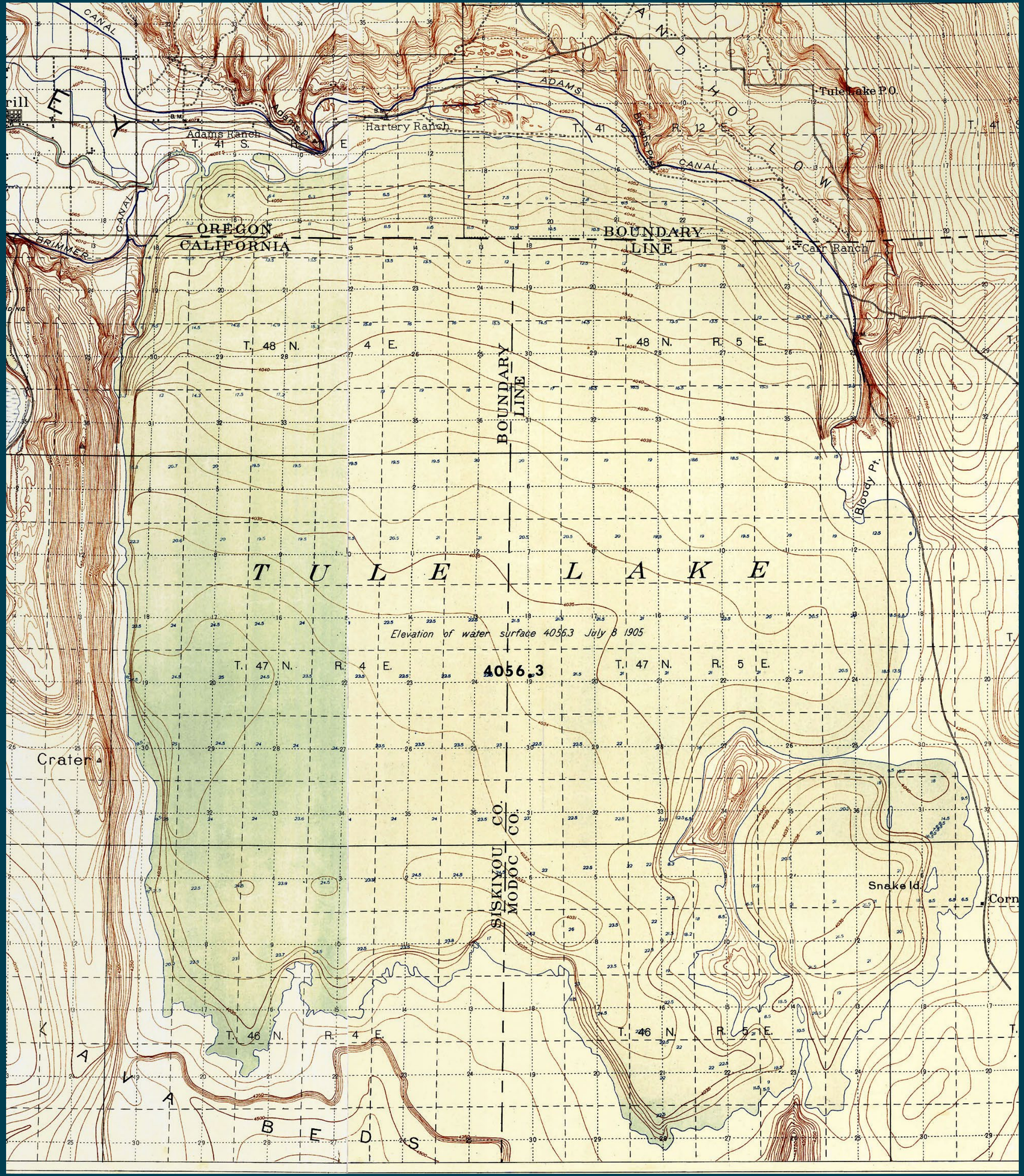


Area-Capacity



Area-Capacity Purpose

- Area-capacity (ACAP) analysis of a topography gives us an understanding of the relationship between the water surface elevation in the lake, the area that water covers, and the volume of water the lake contains
- For Lower Klamath and Tule Lakes, ACAP relationships developed from 1905 contours

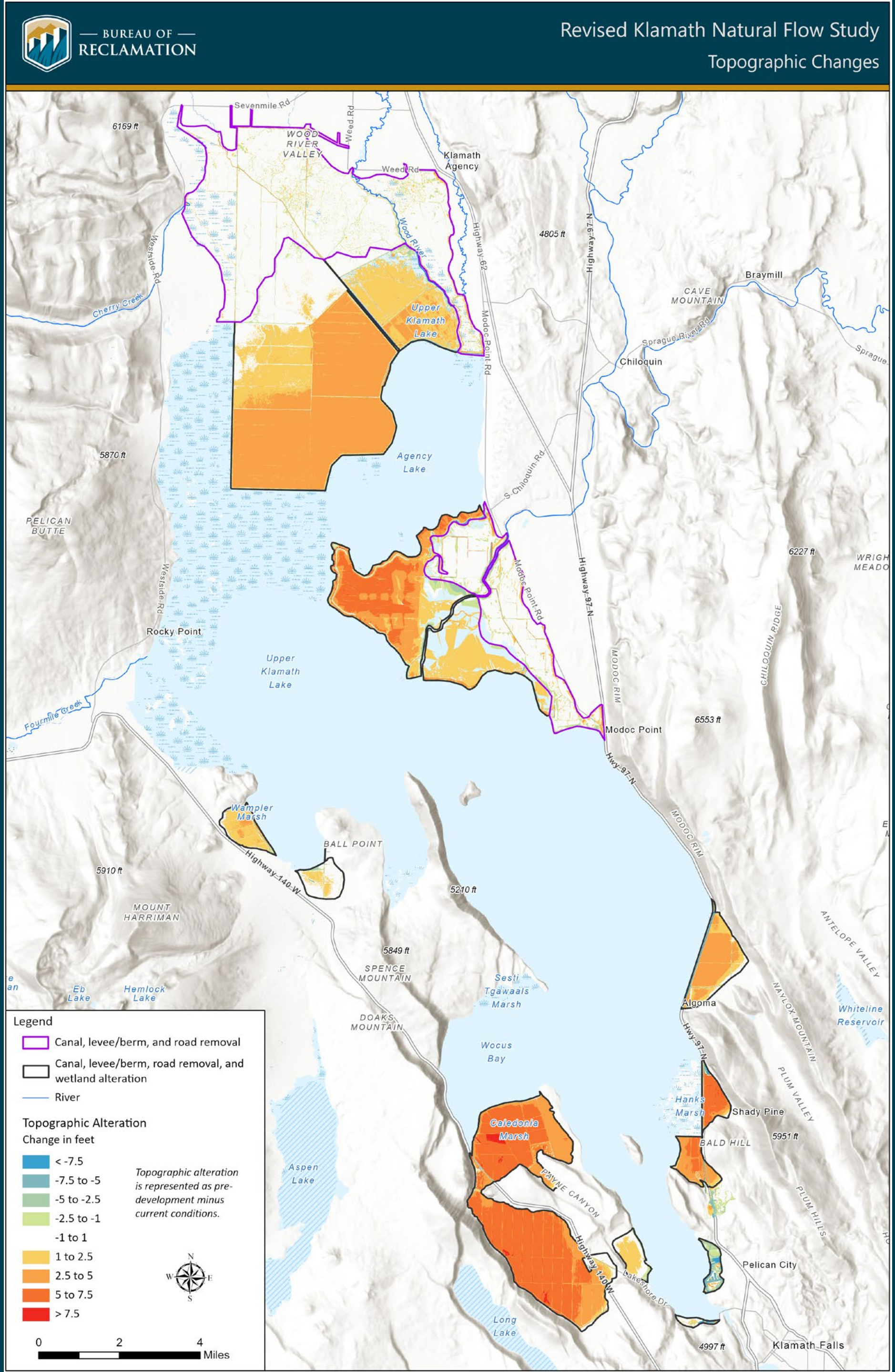


Area-Capacity Methodology

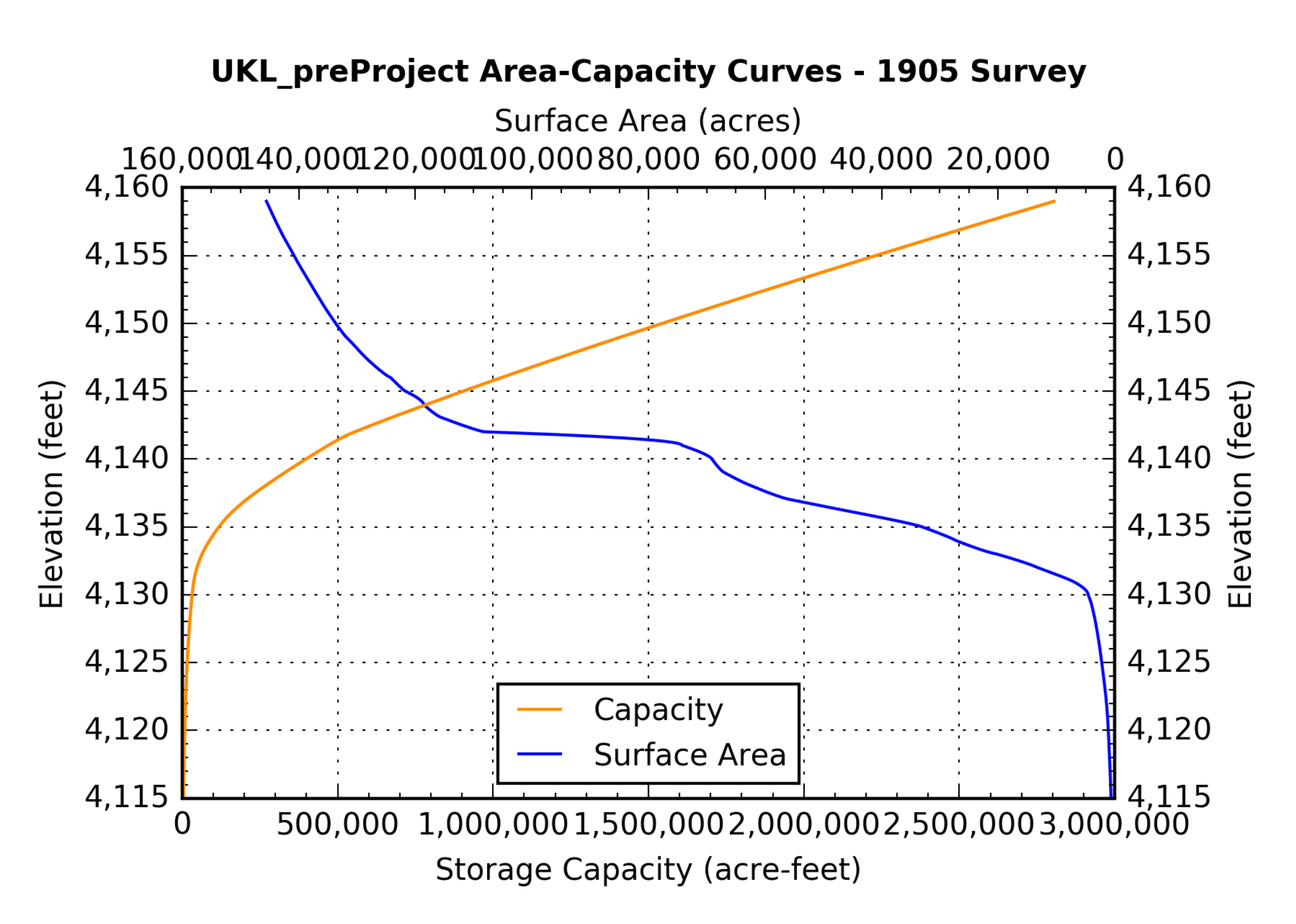
- Data sources for ACAP analysis:
  - UKL
    - 2020 LiDAR
    - 2021 Bathymetric Survey
- Use established calculation methods to determine area and volume totals at each water surface elevation
- Calculations are performed geospatially within ArcGIS Pro

Upper Klamath Lake ACAP Development

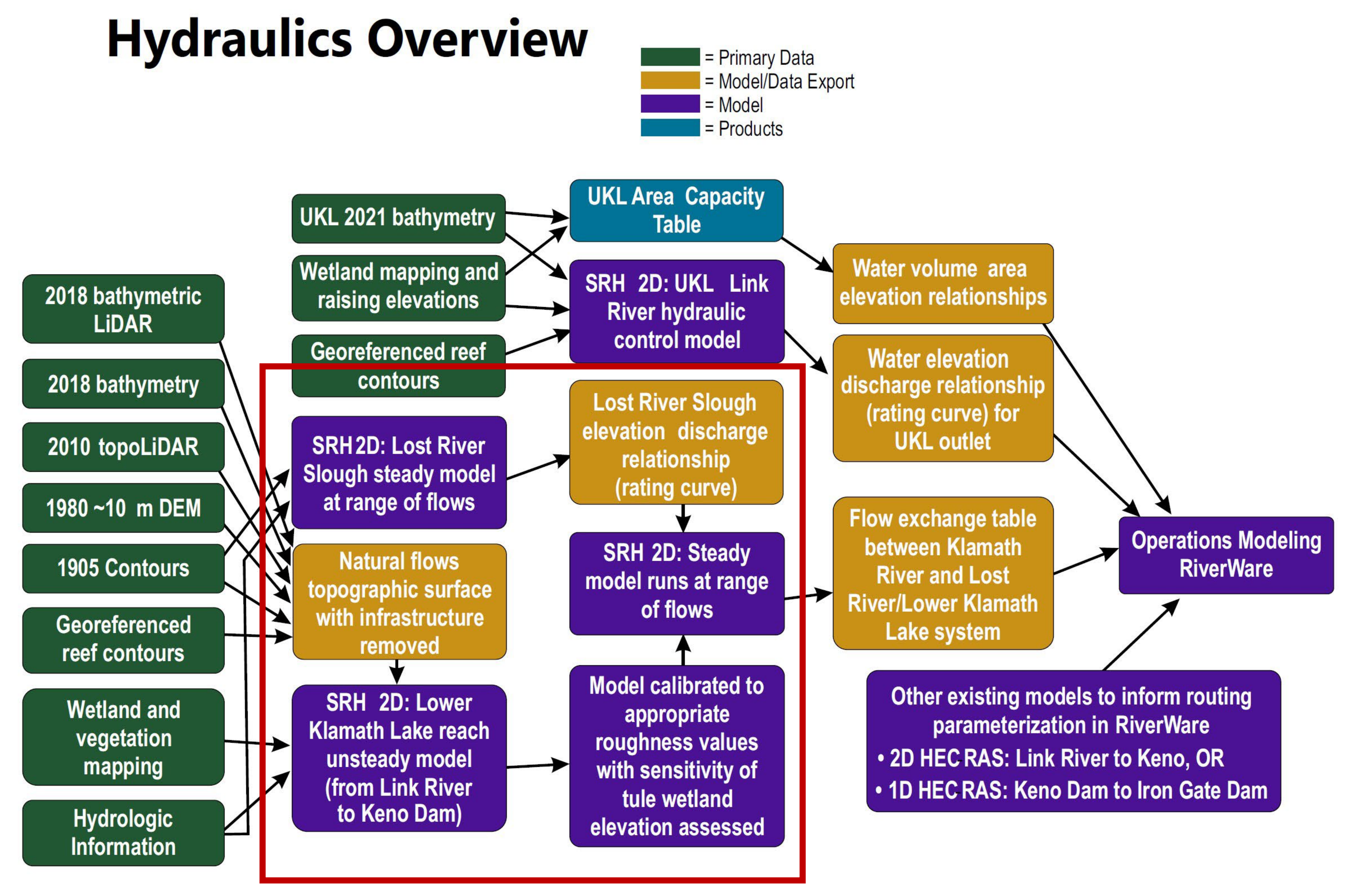
- For current conditions, wetland areas have been calibrated based on comparison of field-surveyed and LiDAR return elevations
- For pre-development conditions leveed locations have been reassigned wetland elevations



Area-Capacity Preliminary Result

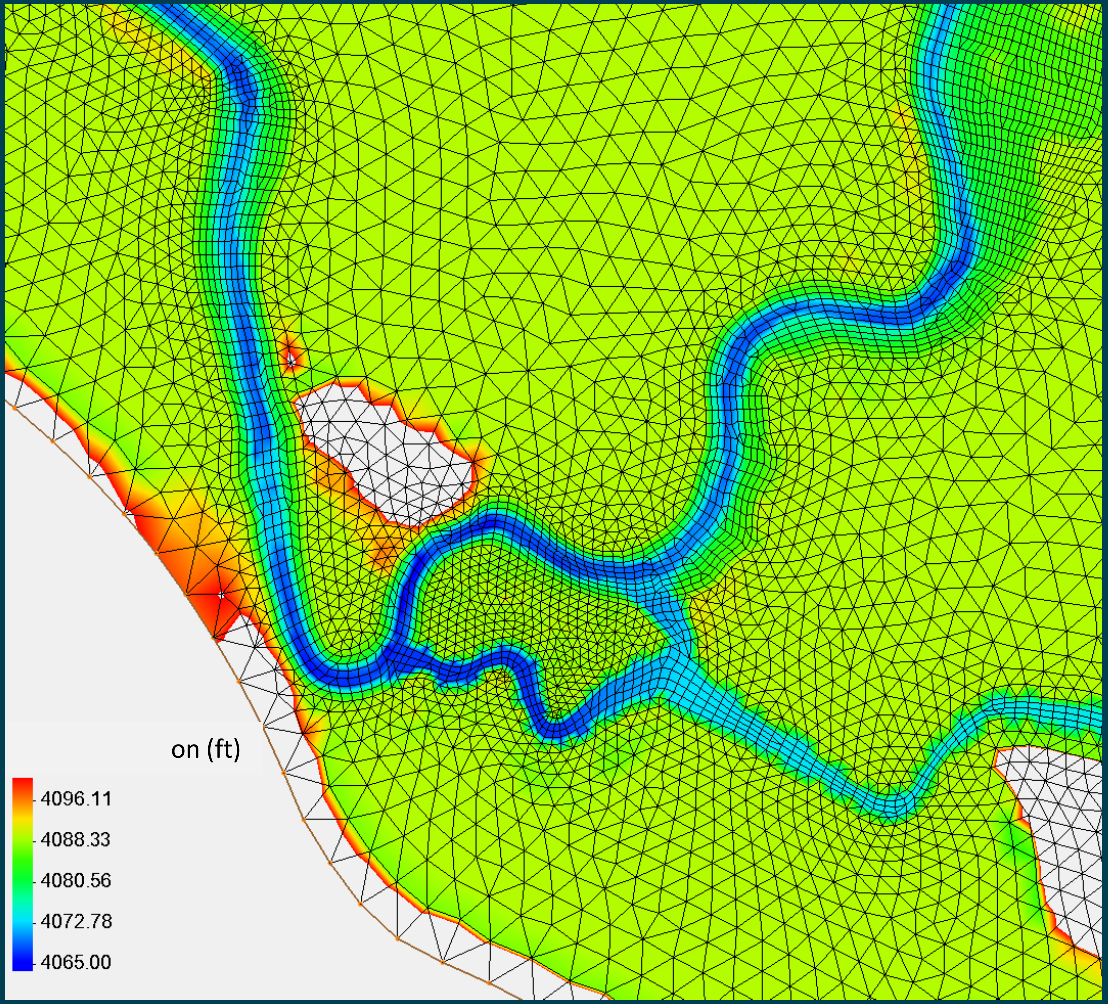


Klamath River – Lower Klamath Lake Model



Hydraulics Model

- 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



Conceptual Hydraulic Relationship between Klamath River and Lower Klamath Lake

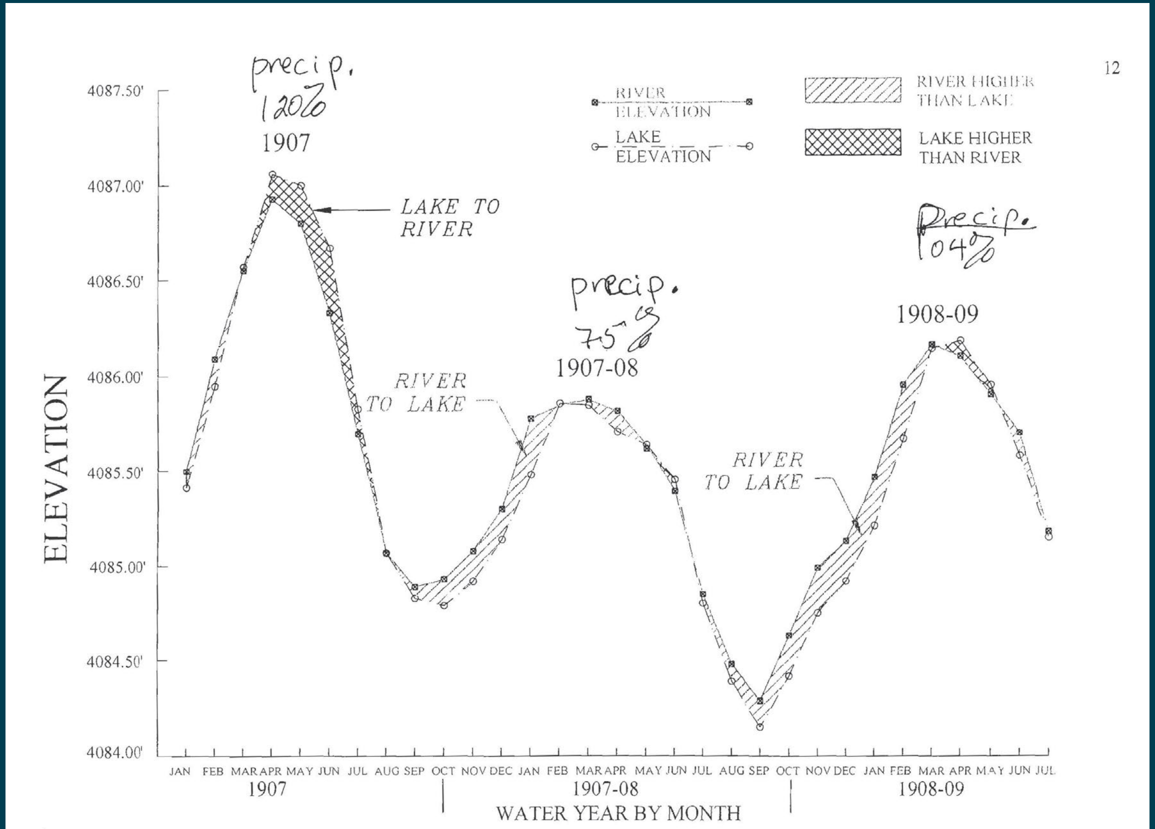


Figure 2. Comparison of Klamath Lake elevations at Brownell and Klamath River elevations at Keno from January 1907 through July 1909, showing major flows from the river to the lake and from the lake to the river. Cross-hatched areas indicate periods when the elevation of the lake surface at Brownell was higher than the elevation of the river at Keno and water flowed from the lake into the river. Single-hatched areas indicate periods when river elevations at Keno exceeded lake elevations at Brownell and water flowed into Klamath Lake. (Based on information in Henshaw and Dean 1915:681-686.)

Source: Weddell, 2000

- 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 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
- Will be included in final modeling effort

Hydraulic Analysis of LKL Connection

Problem:

- We can't model long-term time-series flows with a two-dimensional model like SRH-2D as computational requirements would be too high
  - Example: Current model runs hydraulics at 1-2 months model time per day of computational time. For a 40-year daily time-series that would take 240 days computationally
- Since the lake doesn't drain/evaporate completely on an annual basis, hysteresis likely plays a role in the connection. This means that for any change in beginning condition a different end result could be found
  - With long run times, can't test uncertainty as well

Hydraulic Analysis of LKL Connection

Solution:

- Run two-dimensional hydraulic model for certain lake conditions and river flows
- Create a simplified flow transfer relationship between the river and lake
- 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

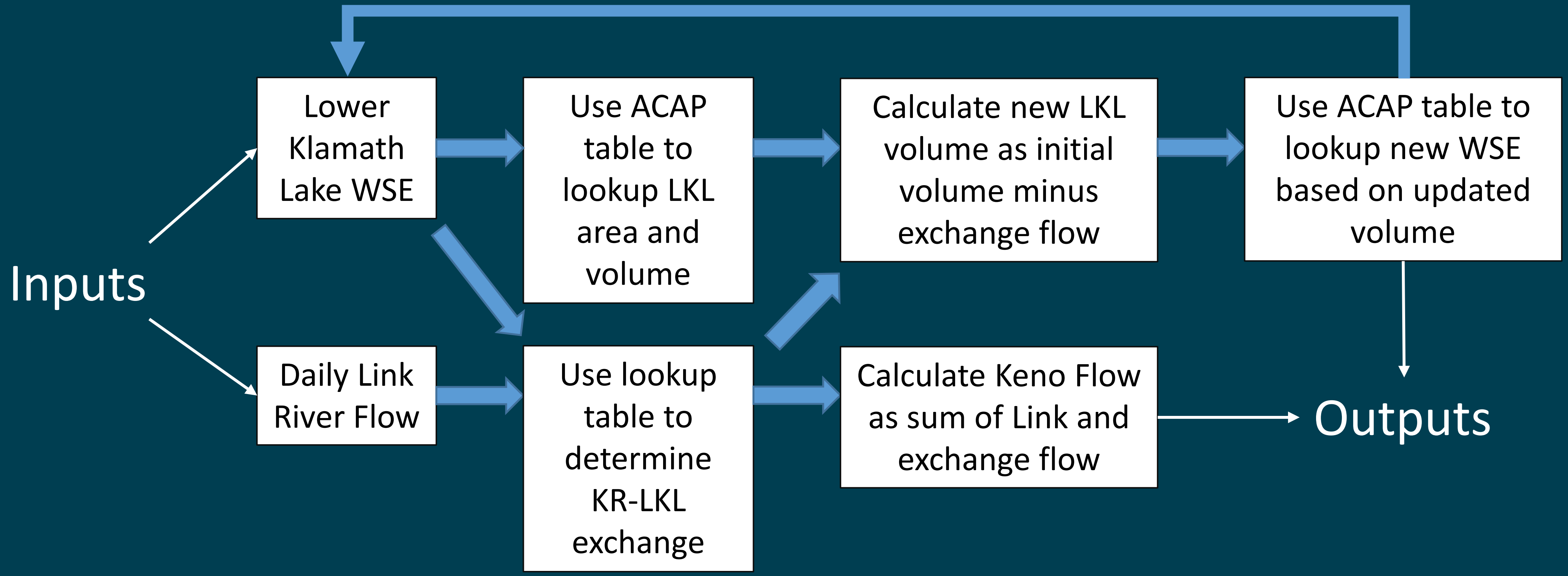
Klamath River Flow (cfs)	LKL Water Surface Elevations				
	4080	4080.5	…	4086.5	4087
500	0	0	…	1600	2000
1000	-100	-90	…	1500	1800
…	…	…	…	…	…
7500	-1800	-1500	…	0	20
8000	-2000	-1750	…	-20	0

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

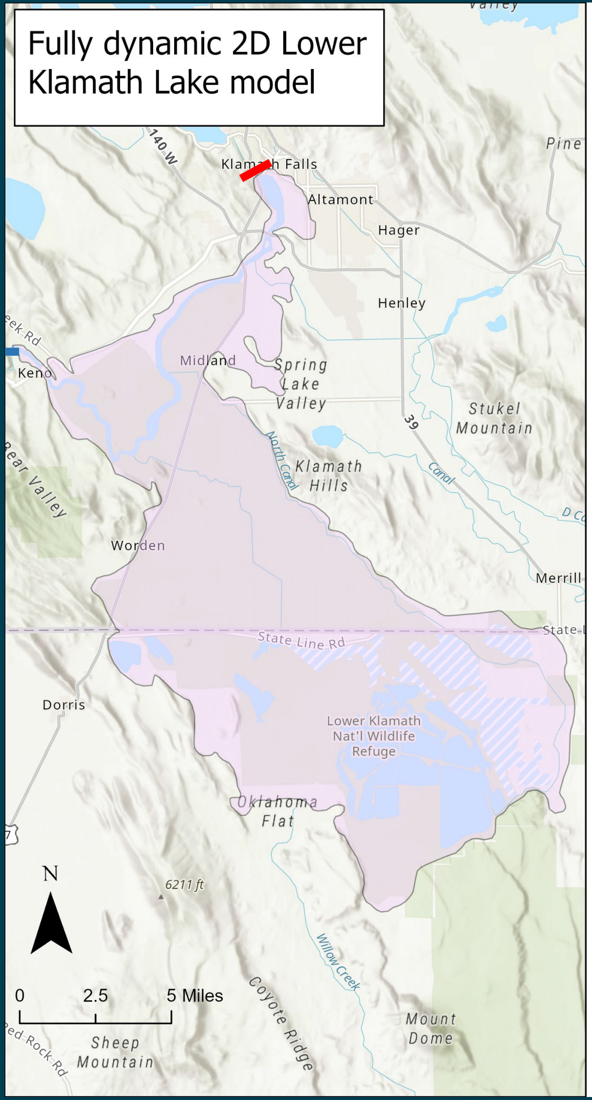
Flow (cfs) contributed to the Klamath River

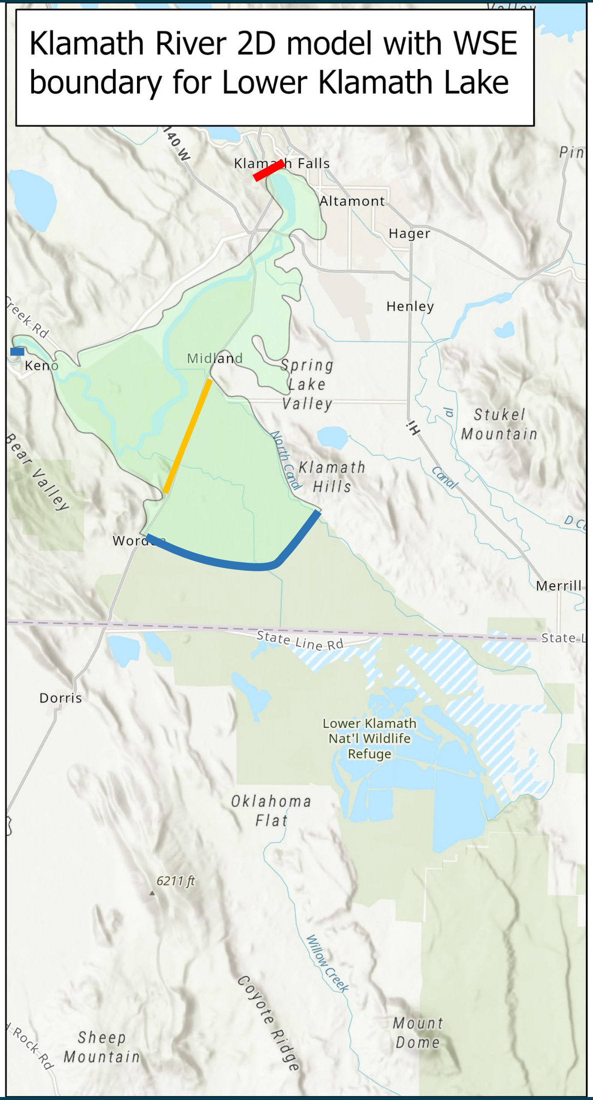
- Negative – flow from river to LKL
- Positive – flow from LKL to river

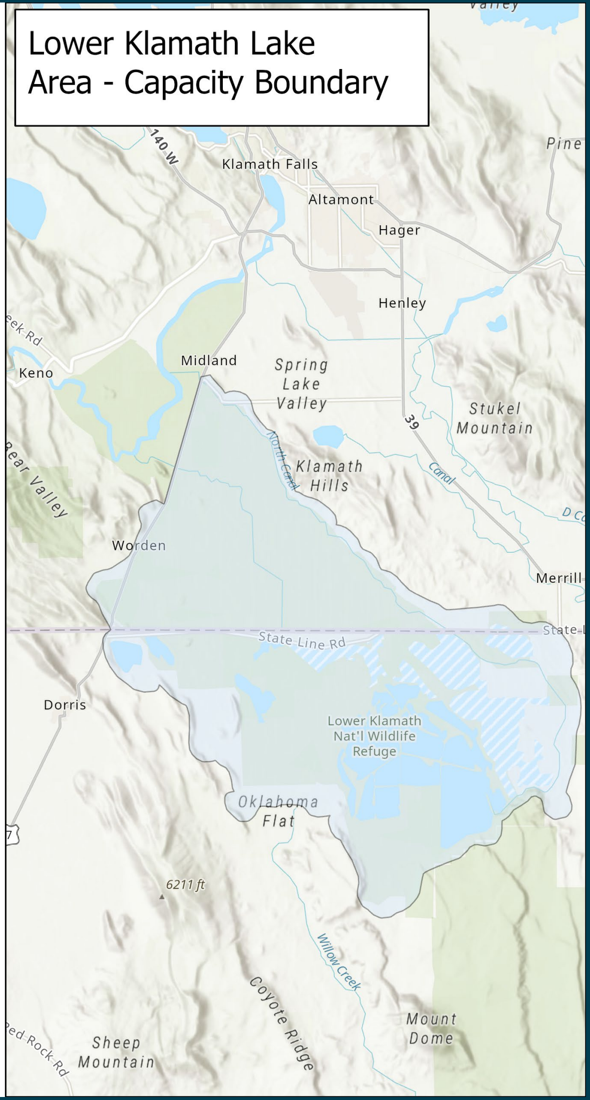
Workflow of Quasi-Unsteady Code



Lower Klamath Lake Modeling







Klamath River – Lower Klamath Lake Exchange Table

Klamath River Flow at Link River (cfs)

Lower Klamath Lake Water Surface Elevation (ft; NAVD88)

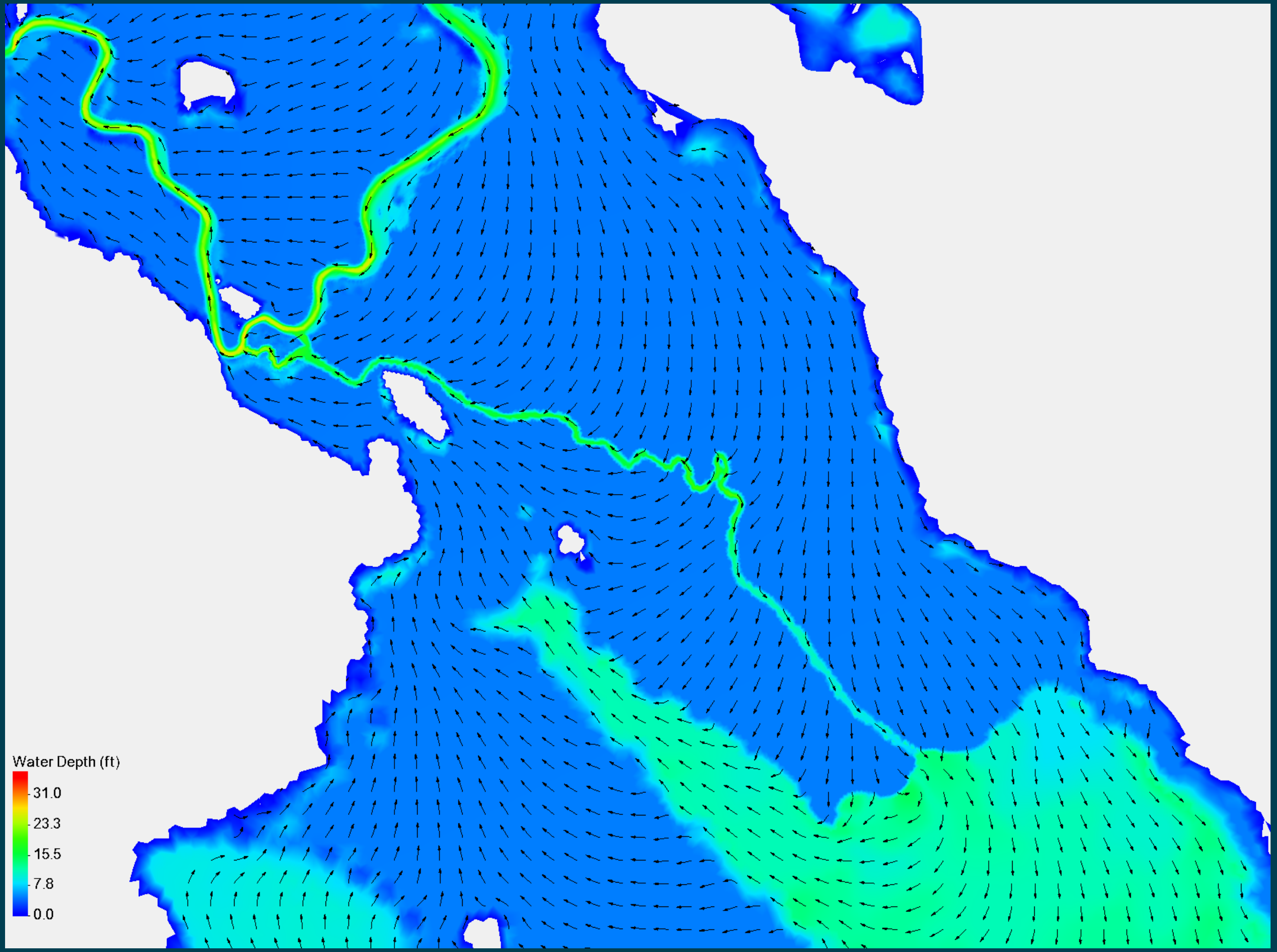
	4085.54	4086.14	4086.64	4087.09	4087.47	4087.84	4088.19	4088.53	4088.83	4089.1	4089.43	4089.69
500	0	82	228	390	563	745	938	1130	1304	1581	1697	1881
1000	-219	-14	170	333	498	675	865	1053	1227	1502	1621	1805
1500	-250	-146	-7	228	401	582	772	960	1134	1410	1550	1741
2000	-290	-264	-210	-4	256	456	654	850	1029	1300	1458	1660
2500	-400	-383	-347	-250	-27	282	506	716	903	1174	1323	1530
3000	-500	-493	-473	-412	-293	-29	307	550	753	1025	1127	1331
3500	-630	-619	-598	-554	-470	-317	-24	333	566	851	874	1067
4000	-750	-738	-722	-688	-625	-513	-336	-7	331	625	558	729
4500	-870	-861	-845	-819	-768	-683	-551	-349	-38	326	184	323
5000	-995	-982	-968	-950	-908	-840	-732	-580	-385	-94	120	-94
5500	-1110	-1102	-1090	-1077	-1043	-988	-903	-784	-643	-473	0	-442
6000	-1130	-1229	-1228	-1214	-1191	-1146	-1081	-988	-878	-767	-500	-33

*Each Cell of table is the exchange rate between the Klamath River and Lower Klamath Lake

Because flows and WSE end up between the values in the row and column headers, interpolated values using a bilinear weighted mean

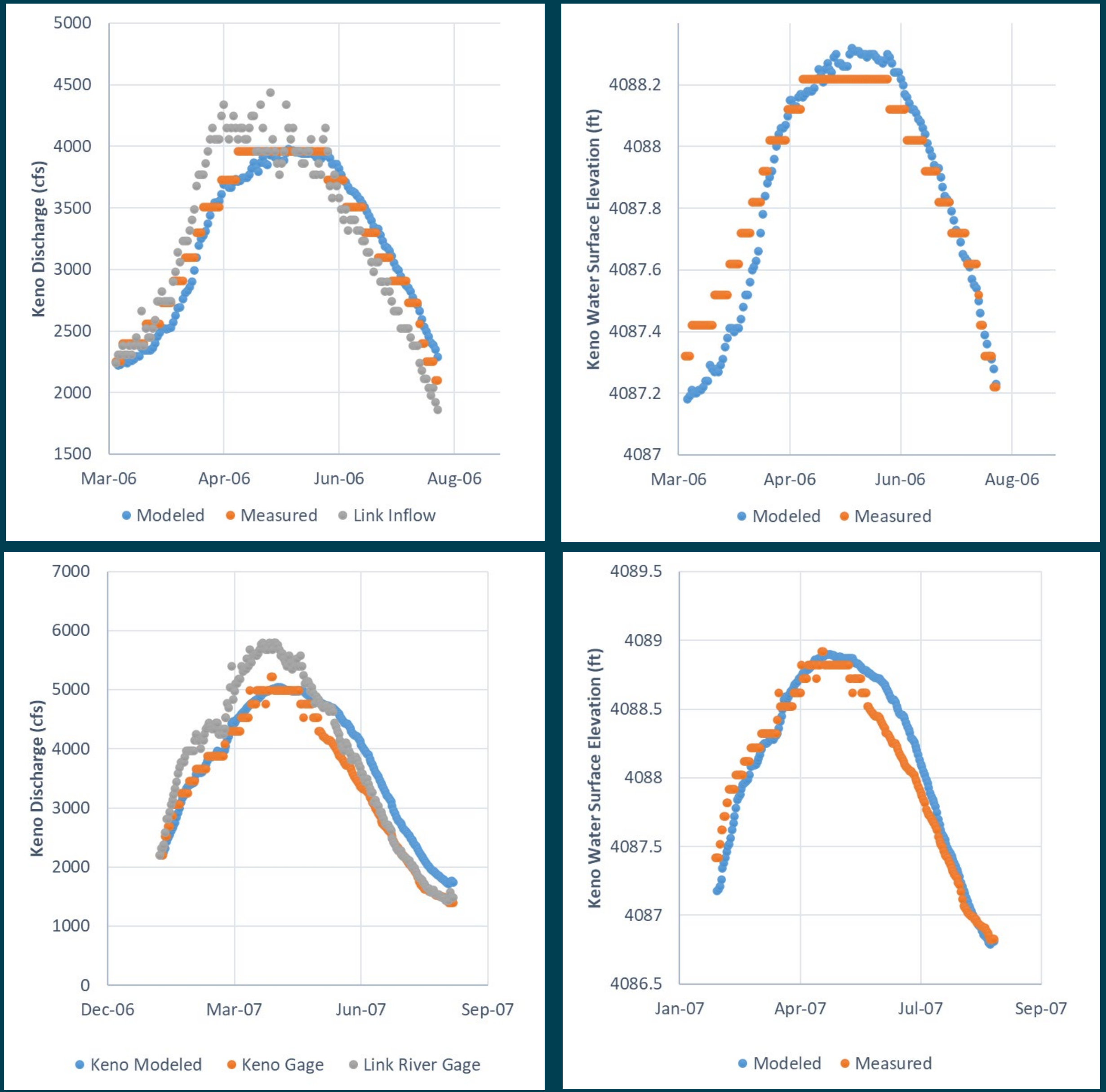
Modeling Methodology

- Develop Terrain
  - 1905 survey, Keno reef contours, 2018 bathymetry, 2018 bathymetric LiDAR, 2010 LiDAR
- Roughness parameterization
  - Tule marshes have most influence on overbanking flow
- Assign boundary conditions
  - Upstream flows from Henshaw & Dean from 1904-1908

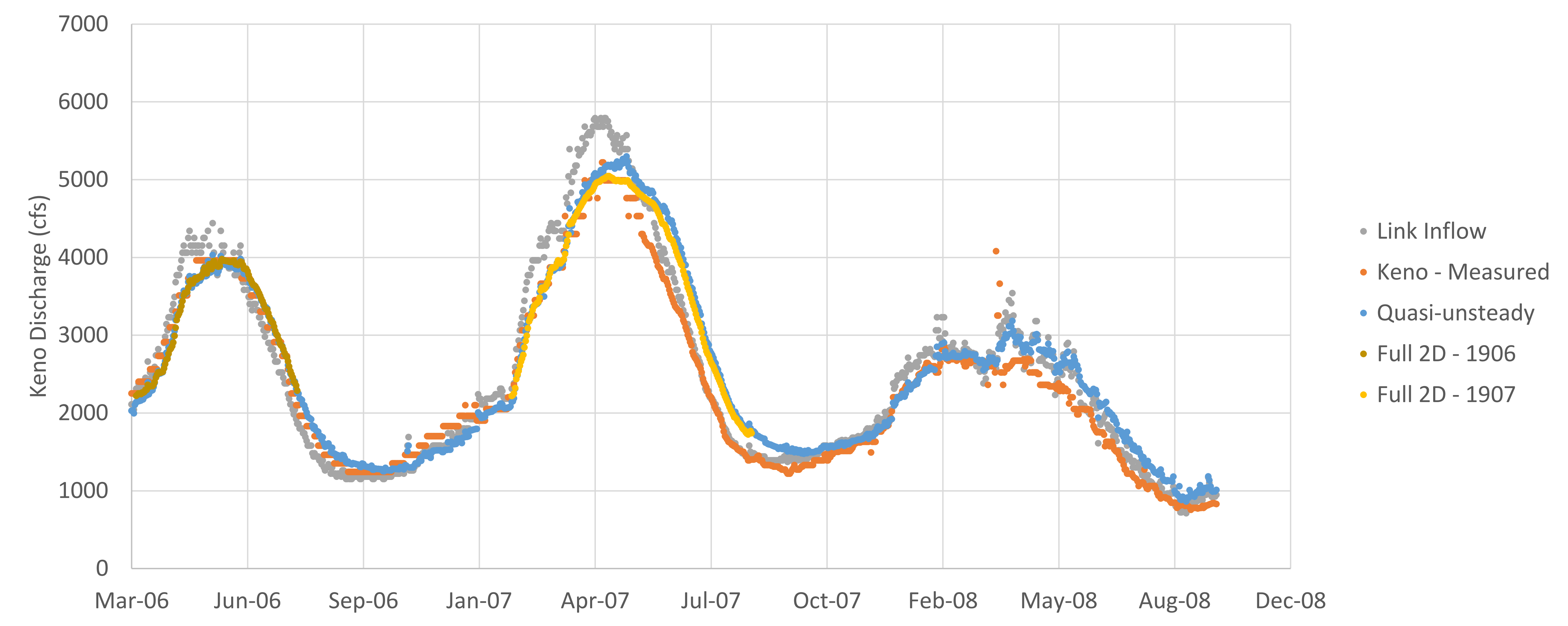


Model Calibration and Verification

- 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

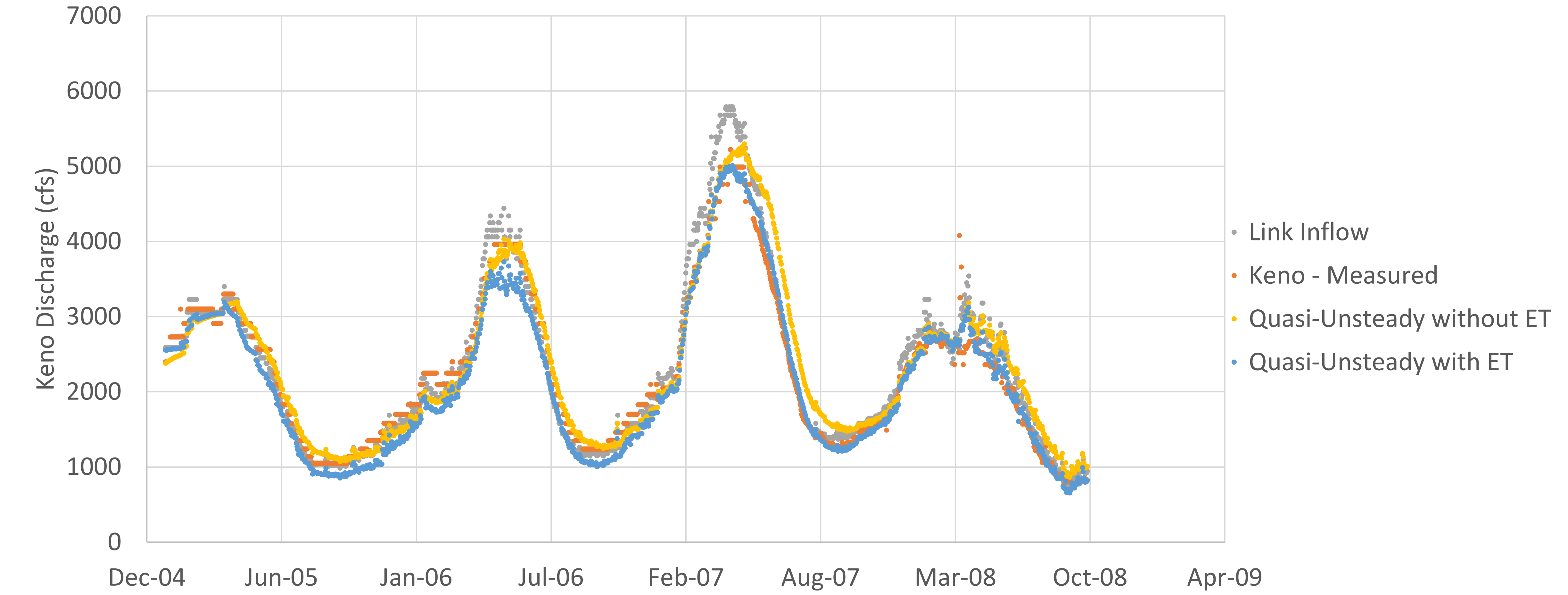


Quasi-Unsteady Calculation



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

Quasi-Unsteady Calculation with ET



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

Comparison to 2005 Natural Flow Study

2005 Study

- Upper Klamath Lake ACAP
  - Based on area-water surface elevation relationship above outlet reef
- Upper Klamath Lake Outflow
  - Evaluated from historical monthly lake WSE and discharge data
- Lost River Slough
  - Not accounted for
- Lower Klamath Lake
  - Used a correlation approach between flows at the Link River and Keno gages between 1904 and 1918

Current Study

- Upper Klamath Lake ACAP
  - New bathymetric and LiDAR surveys with wetland sensitivity adjustment
- Upper Klamath Lake Outflow
  - 2D model used to develop rating curve between UKL WSE and outflow
- Lost River Slough
  - 2D model to develop rating curve of Klamath River WSE and LRS outflow
- Lower Klamath Lake
  - Quasi-unsteady approach used to develop flow exchange between Klamath River and LKL

Natural Flow Representation

- Upper Klamath Lake
  - Roads, levees, berms, and canals have been removed from terrain in locations where the infrastructure would impact the ACAP analysis
  - Locations that are behind levees under current conditions but were wetlands in pre-development conditions were adjusted to wetland elevations
- Lower Klamath Lake model and ACAP, Lost River Slough model, and Tule Lake ACAP
  - All infrastructure is removed from locations using 1905 contours
  - In locations with LiDAR data sources, infrastructure adjusted to surrounding elevations
- Bedrock reefs have been reconstructed based on historical reports or dam design drawings

Sensitivity & Uncertainty Analysis

- Model and ACAP sensitivity to tule marsh elevation is being tested
- Model sensitivity and uncertainty bounds in relation to model roughness values will be tested
- Quasi-unsteady model will be tested for uncertainty in starting Lower Klamath Lake water surface elevation and relationship to evapotranspiration

Summary

- Hydraulics study encompasses several tasks including ACAP, rating curve, and flow exchange rates
  - Datasets include historical contours, LiDAR, bathymetric surveys, flow, and water surface elevation data
  - Calibrated to historical datasets
- Improved upon the 2005 Study by:
  - Including new LiDAR and bathymetry datasets
  - Developing 2D models to inform Upper Klamath Lake outflow, Lost River Slough outflow, and exchanges between the Klamath River and Lower Klamath Lake
- Natural flow represented by:
  - Removing infrastructure surrounding Upper Klamath Lake and altering elevations to estimate wetland elevations
  - Using 1905 topo-bathymetry to develop models and ACAPs for Lower Klamath Lake and Tule Lake
  - Reconstructed reefs that provided hydraulic controls on Upper Klamath Lake and the Klamath River

Questions and Additional Discussion

Colin Byrne
cbyrne@usbr.gov

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