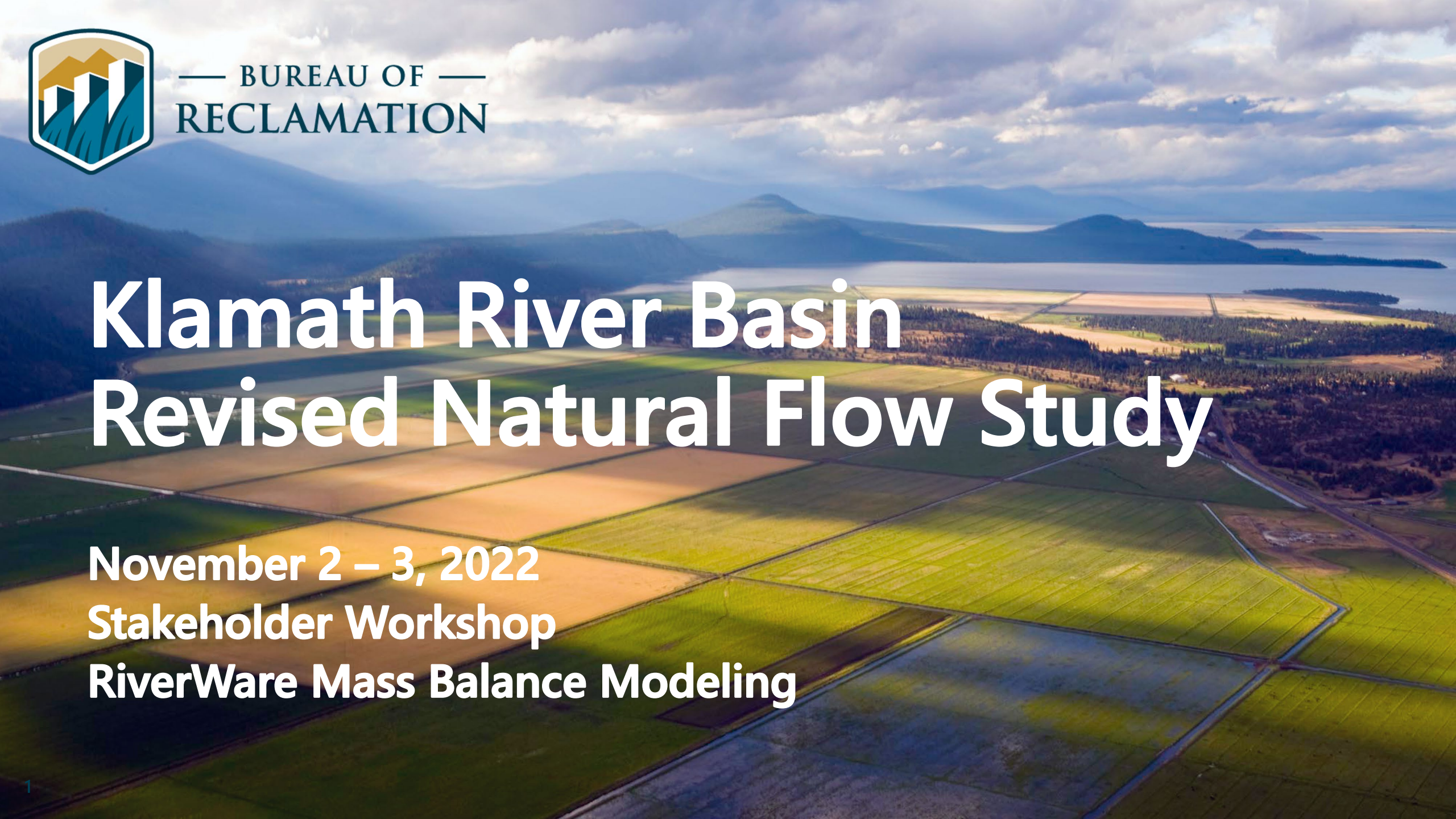


Klamath River Basin Revised Natural Flow Study

November 2 – 3, 2022
Stakeholder Workshop
RiverWare Mass Balance Modeling

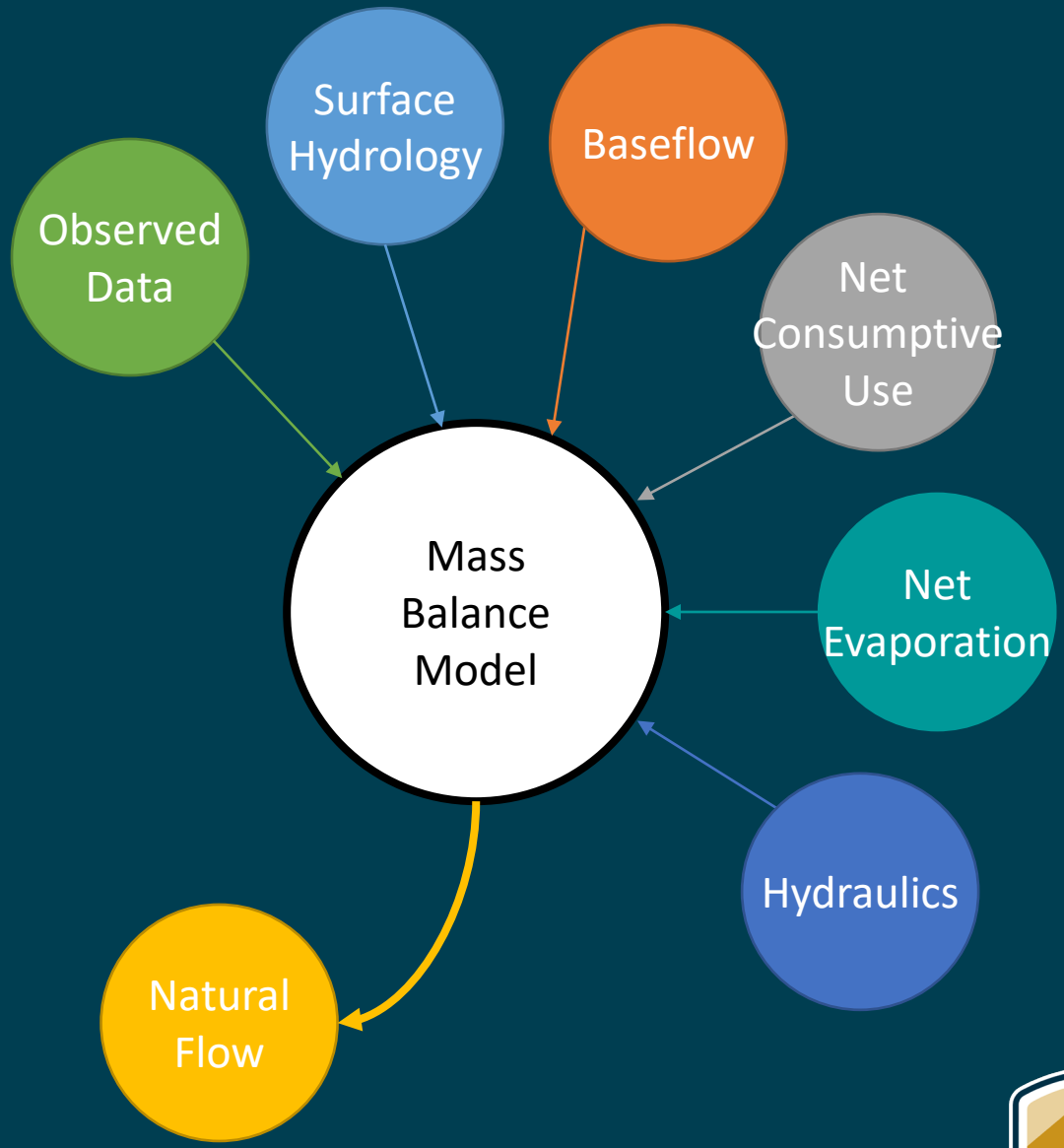
Outline

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

Model Purpose

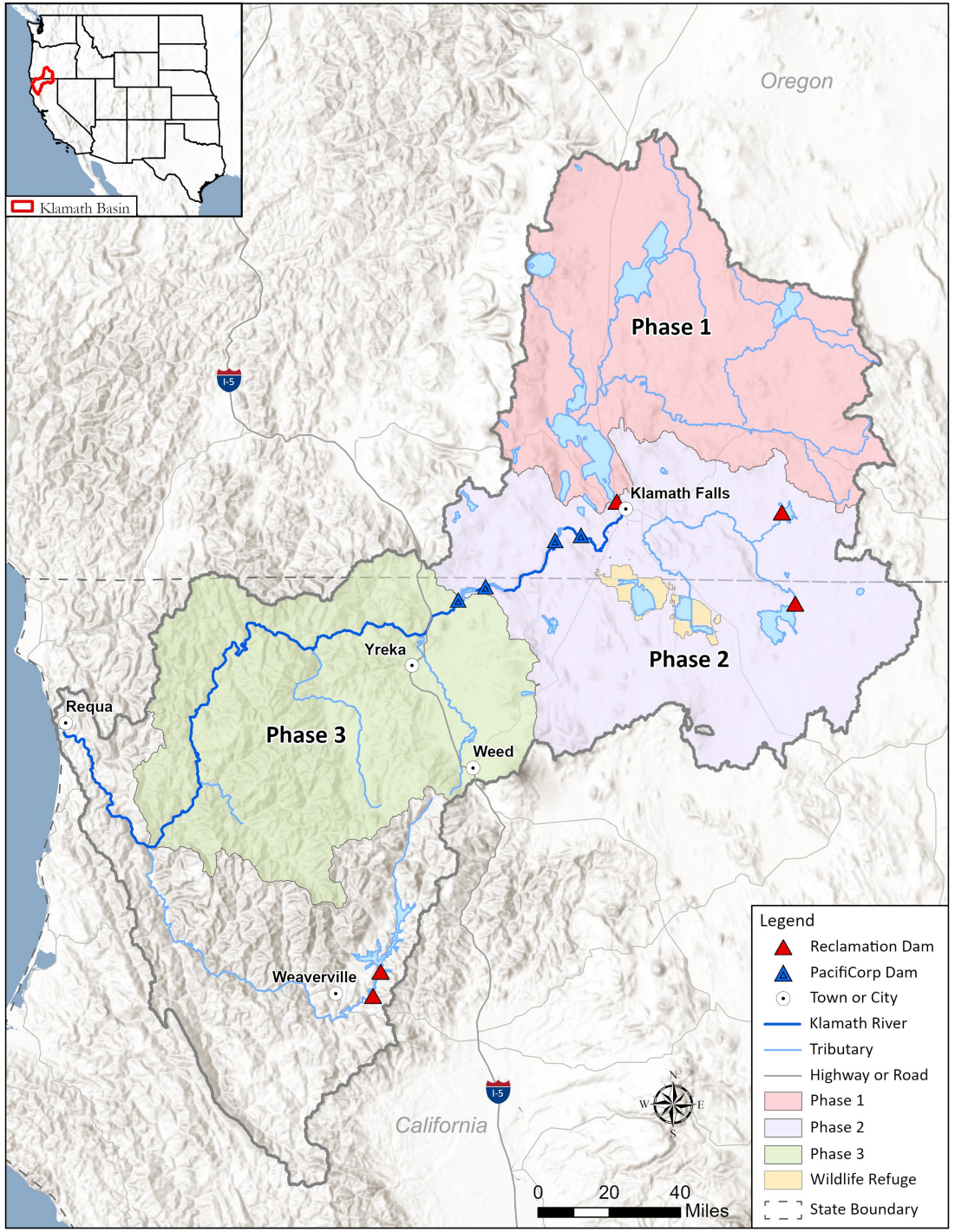
- The purpose of the RiverWare Mass Balance Model is to integrate
  - modeled surface hydrology
  - baseflow
  - consumptive use
  - open water evaporation, and
  - hydraulics

  to develop natural streamflow estimates, assuming pre-development conditions



Model Extent

- Phase 1
  - Incorporates drainage area upstream of Link River at Klamath Falls
- Phase 2
  - Incorporates modeling of Lost River, Klamath Project, Lower Klamath NWR
  - Incorporates mass-balance of Rogue River Project interbasin transfers
- Phase 3
  - Scott, Shasta, other lower basin tributaries

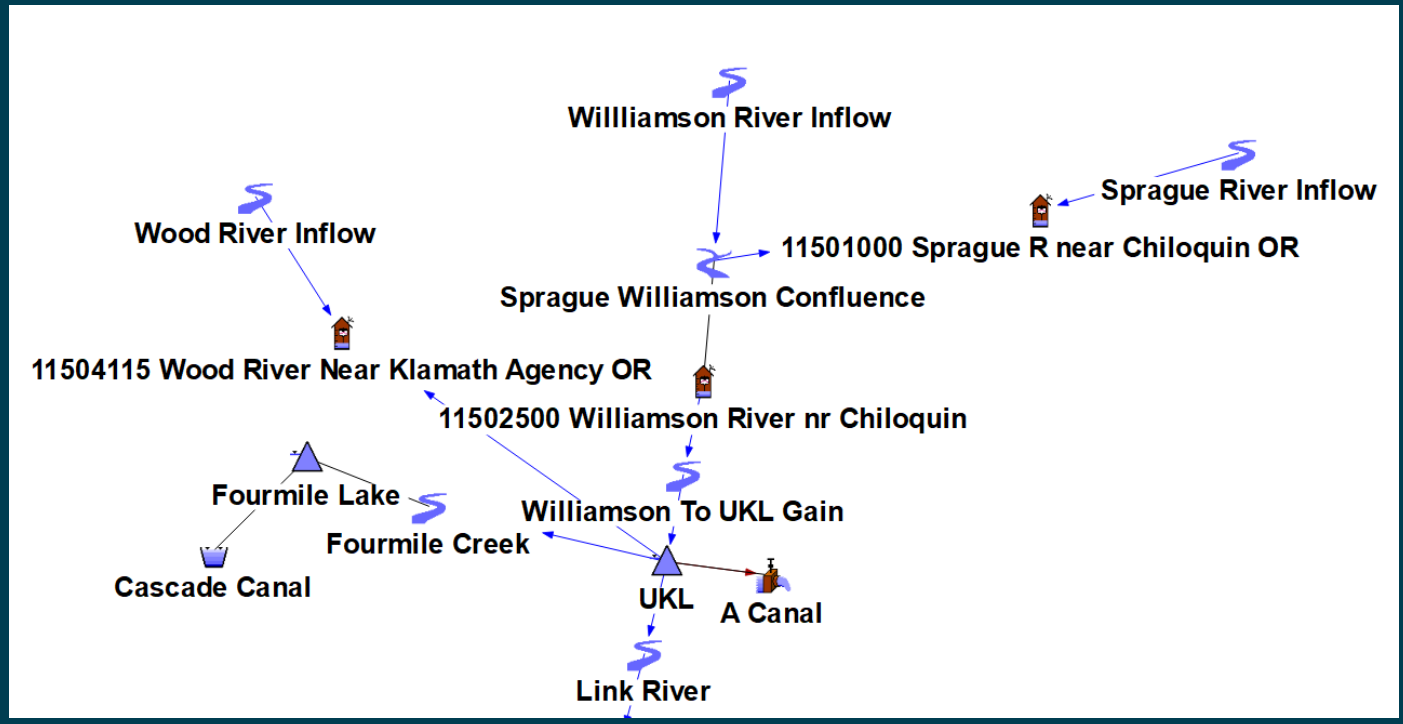


Study Locations

USGS ID	Description
11501000	Sprague River near Chiloquin, OR
11502500	Williamson River below Sprague River near Chiloquin, OR
11507500	Link River at Klamath Falls, OR
11504115	Wood River near Klamath Agency, OR
11509500	Klamath River at Keno, OR
11510700	Klamath River below JC Boyle Powerplant near Keno, OR
11516530	Klamath River below Iron Gate Dam, CA
11517500	Shasta River near Yreka, CA
11519500	Scott River near Fort Jones, CA
11520500	Klamath River near Seiad Valley, CA
11523000	Klamath River at Orleans, CA
Not Applicable	Klamath River at Weitchpec, CA

Klamath Mass Balance Model

- The Mass Balance Model uses RiverWare, a modeling framework that calculates the water balance of a managed water resources system using a prioritized list of operational rules and tailored methods for river and reservoir routing, quantifying evaporation volume, and more



Draft of model schematic for Phase 1 region

RiverWare

Center for Advanced Decision Support for Water and Environmental Systems (CADSWES)

UNIVERSITY OF COLORADO **BOULDER**

Who uses RiverWare?

Bureau of Reclamation – 27 offices

Tennessee Valley Authority – River Operations, Knoxville, TN

U.S. Army Corps of Engineers - 13 offices

10 Federal Agencies, Tribes and research labs

31 State, City and District Water Agencies

8 Electric Utilities – US and Canada

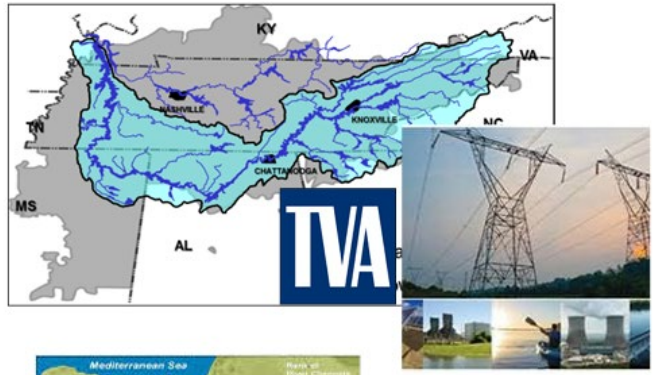
23 Consulting companies and NGOs

12 Universities and research groups

19 Foreign Entities

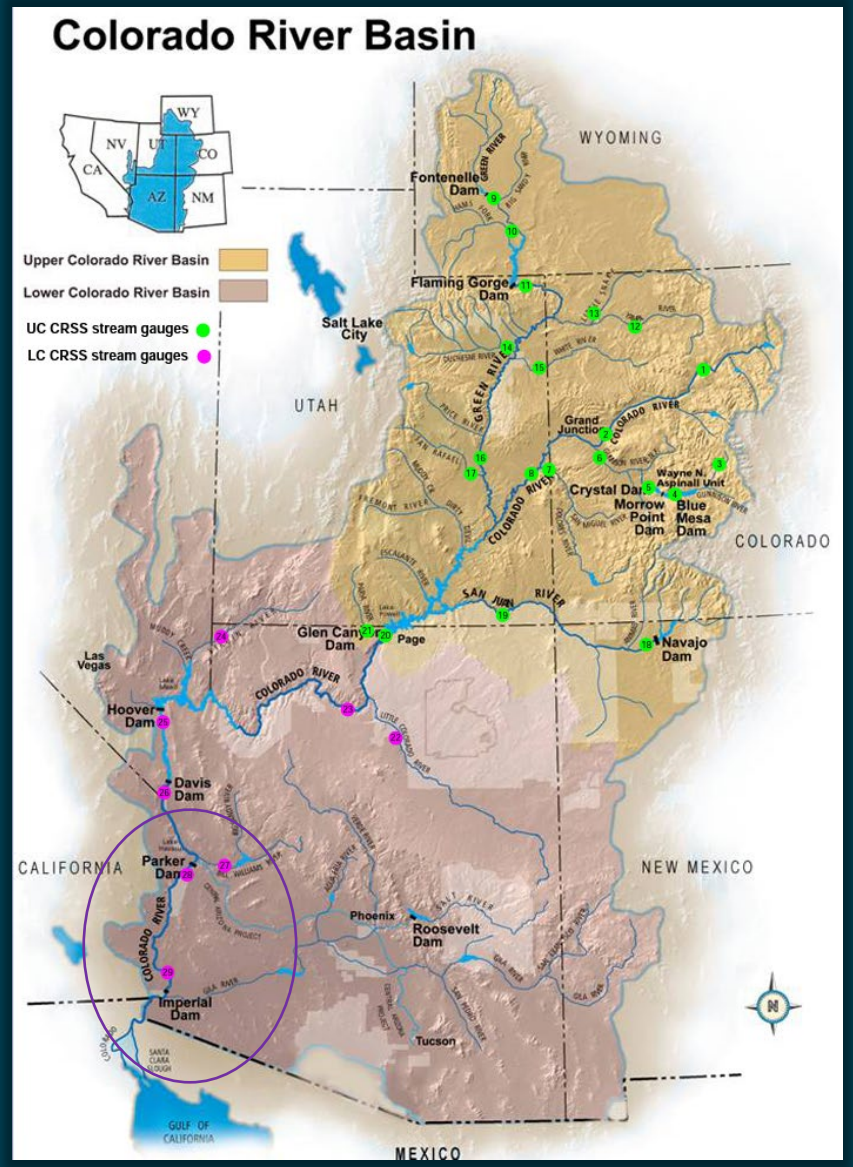
Colorado River Basin

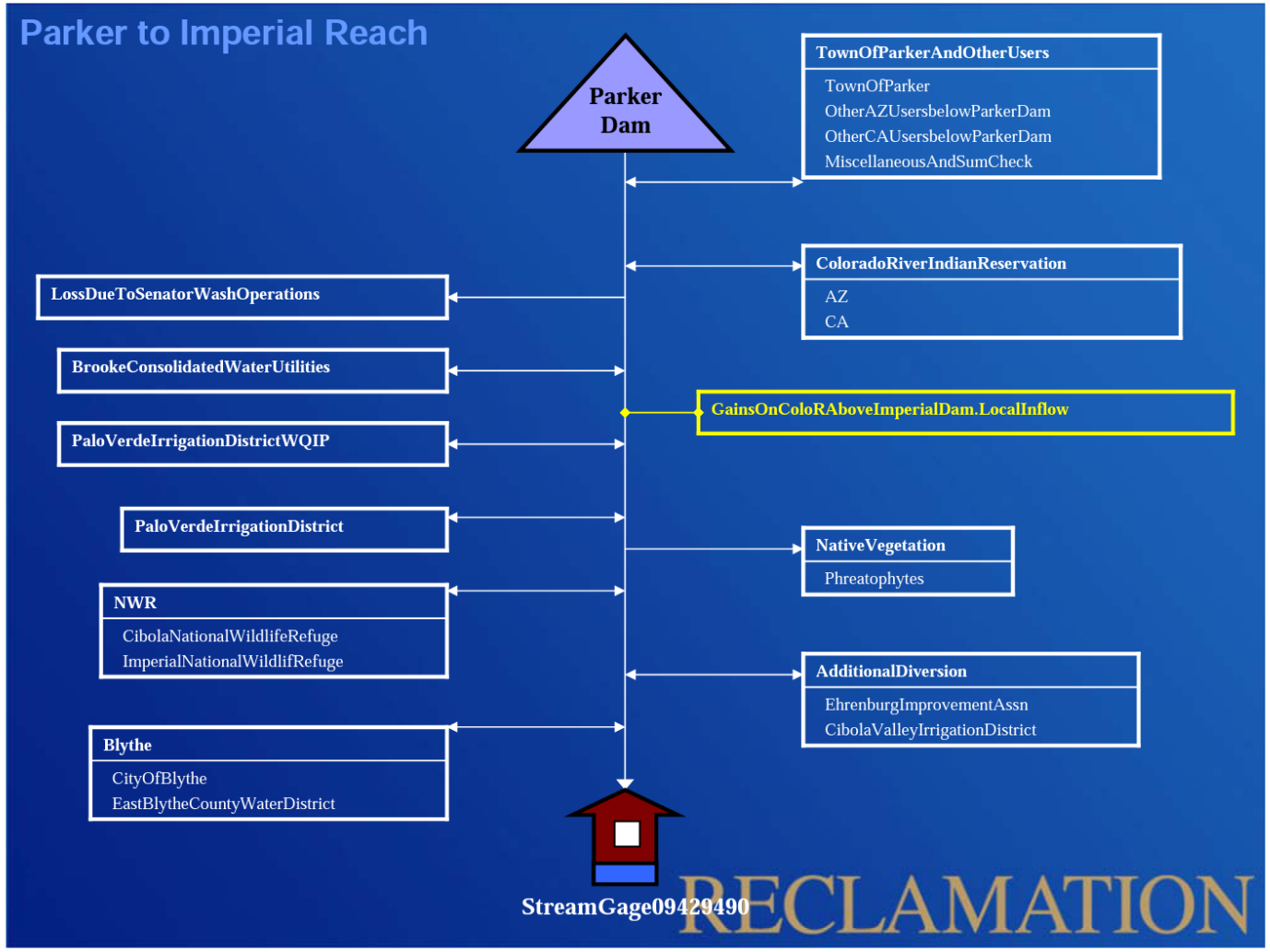
Drought Contingency Plan
Tribal Water Agreement
Mexico Treaty Minute 323
Upcoming: 2026 guidelines



Nile River Basin

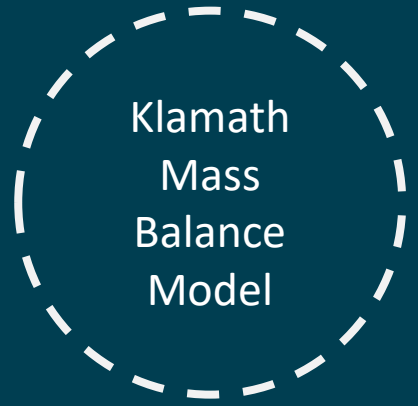
Colorado River Basin Natural Flow and Salt Data





https://www.usbr.gov/lc/region/g4000/NaturalFlow/documentation.html

RiverWare in the Klamath Basin



Daily Operations
(completed 2020)

- *Runs out to ~1 year*
- *Fixed operating policy*
- *Fixed model structure*
- *Observations and forecasts as inputs*

Long-Term Planning
(planned completion 2022)

- *May run years to decades*
- *Varying operating policy*
- *Varying model structure*
- *Historical observations or scenario data as inputs*
  - *e.g. paleohydrology or projected future streamflow*

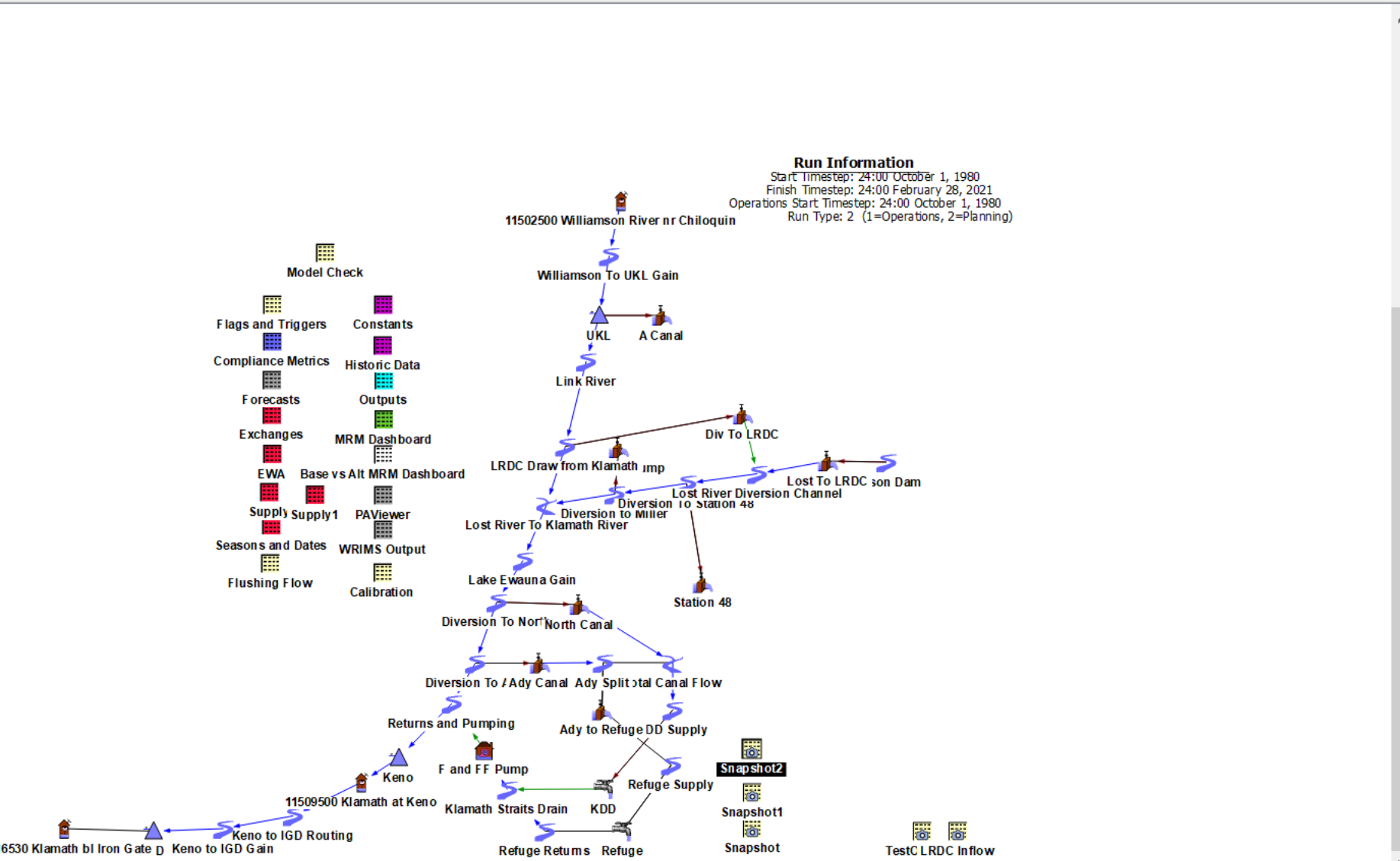
Klamath Revised Natural Flow Study

- *Will run water years 1981-2020*
- *Conceptual model structure*
- *Model objects consistent with KPOM*
  - *e.g. gage objects*
- *Historical observations and modeled historical data as inputs*

RiverWare 8.5.1 - KPOM.mdl [Git branch: KPOM_Development]

File Control Workspace Policy DMI Accounting Utilities Windows Units Scripts Help

Simulation View



Object List

Filter

Sort by Position

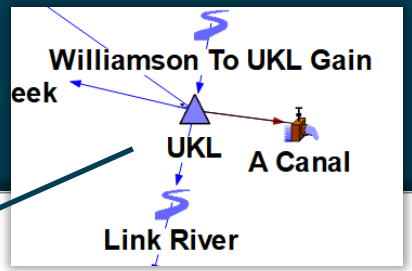
Objects

- 11502500 Williamson River nr Chiloquin
- Model Check
- Williamson To UKL Gain
- Flags and Triggers
- Constants
- UKL
- A Canal
- Compliance Metrics
- Historic Data
- Link River
- Forecasts
- Outputs
- Div To LRDC
- Exchanges
- MRM Dashboard
- LRDC Draw from Klamath
- Miller Hill Pump
- EWA
- Base vs Alt MRM Dashboard
- Lost To LRDC
- Wilson Dam
- Lost River Diversion Channel
- Diversion To Station 48
- Supply
- Diversion to Miller
- Supply1
- PAViewer

Animation Controls

Oct 1, 1980

Object Viewer | Slot Viewers | RPL Viewers | RBS | Opt | RiverWare



Object Viewer

File Edit View Slot Account Group Object Tabs

UKL

Object: UKL

Slots | Methods | Accounts | Accounting Methods | Attributes | Description

September 30, 1980

Slot Name	Value	Units
Ag Demand	NaN	cfs
Ag Override	NaN	cfs
Available for Diversion	NaN	cfs
Canal Flow	NaN	cfs
Central Tendency Elevation	NaN	feet
Central Tendency Parameters		
Convergence Percentage		
Credit	NaN	acre-feet
Credit EWA Spill	NaN	acre-feet
Cumulative Inflow	NaN	acre-feet
Diversion	NaN	cfs
Diversion Capacity	NaN	cfs
Elevation Volume Table		
Fill Release	NaN	cfs
Flood Accounting Switch	NaN	NONE
Flood Elevation Table		feet
Flood Scenario	2.00	NONE
Flushing Flow Max Release	NaN	cfs
Forecast Error	NaN	acre-feet
Formula and Curve Data NOT USED		
Historical Pool Elevation	NaN	feet
Inflow	NaN	cfs
Inflow Adj	NaN	decimal
Inflow Adj Table		
Inflow Exceedance Daily	NaN	decimal

Order: Column Sort Filter Slots

Object Viewer

File Edit View Slot Account Group Object Tabs

UKL

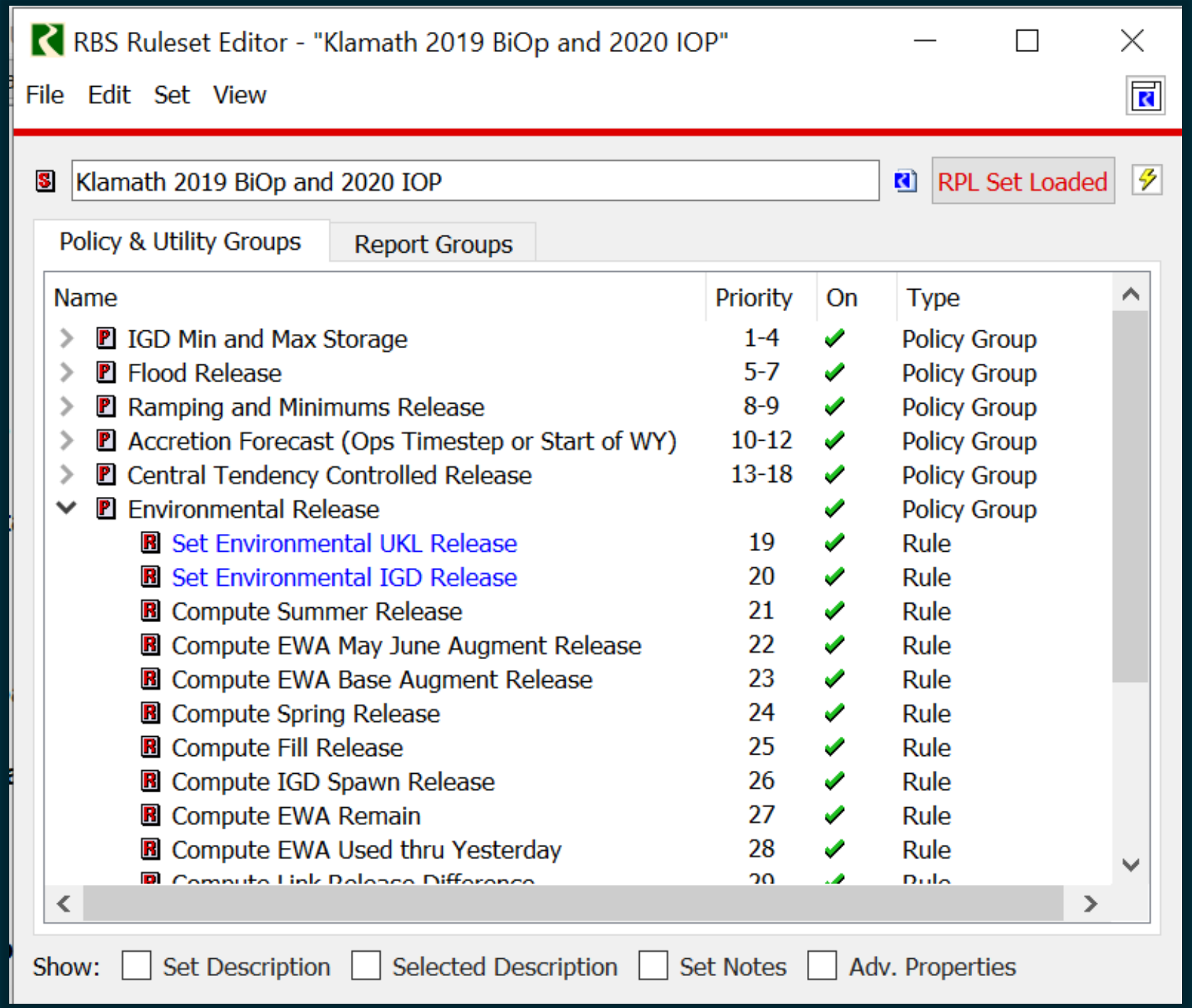
Object: UKL

Slots | Methods | Accounts | Accounting Methods | Attributes | Description

Selected Method: Input Evaporation

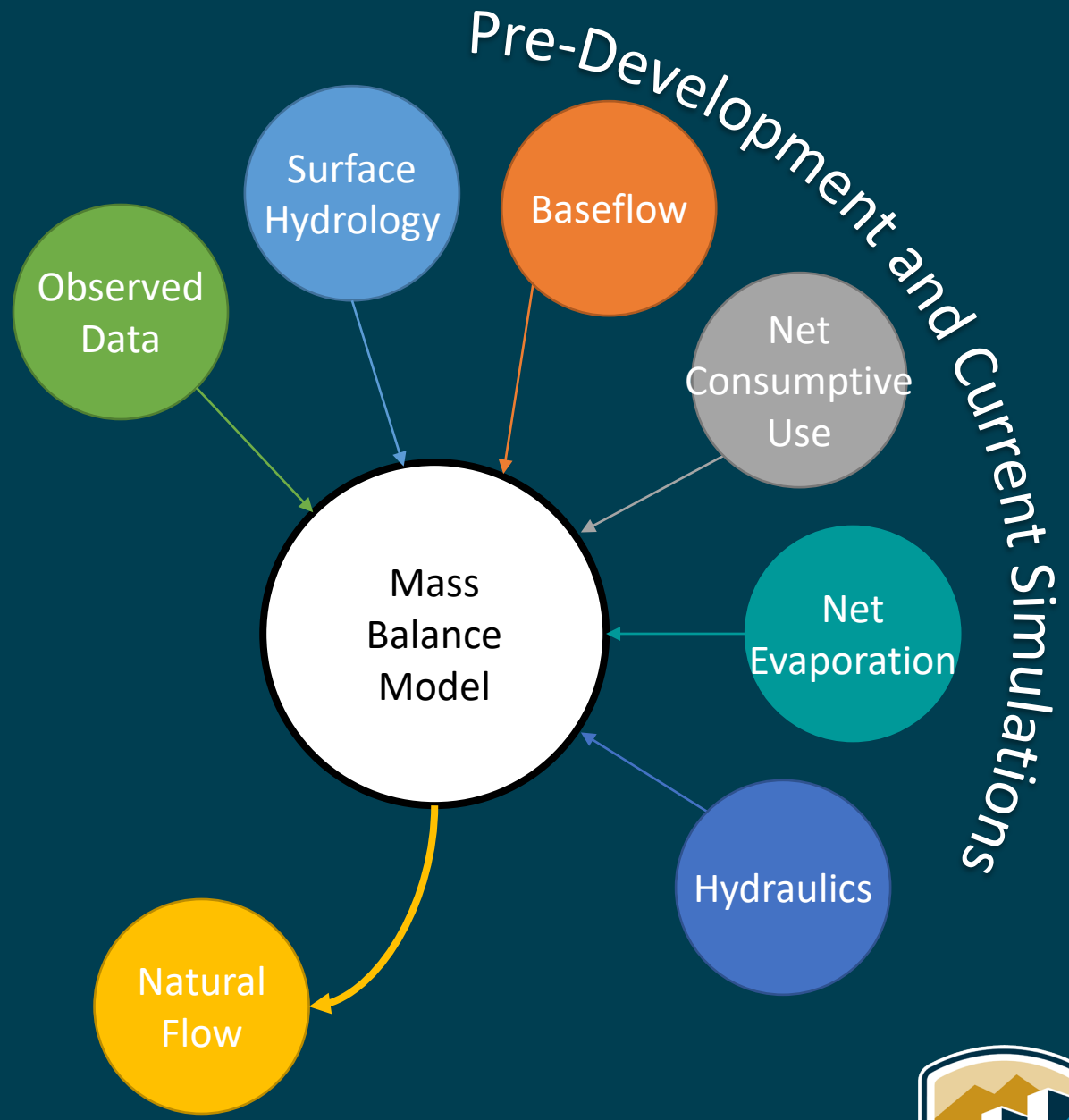
Category	Method
Bank Storage	None
Diversion from Reservoir	Available Flow Based Diversion
Available for Diversion	
Diversion Power	None
Evaporation and Precipitation	Input Evaporation
Elevation Area Table	
Evaporation	
Evaporation Rate	
Precipitation Rate	
Precipitation Volume	
Surface Area	
Evap and Precip Rate Specification	None
Surface Area Modification	None
Hydrologic Inflow	None

The RiverWare Mass Balance will be agnostic to operational rules, because operations will be reflected in the observed input data.



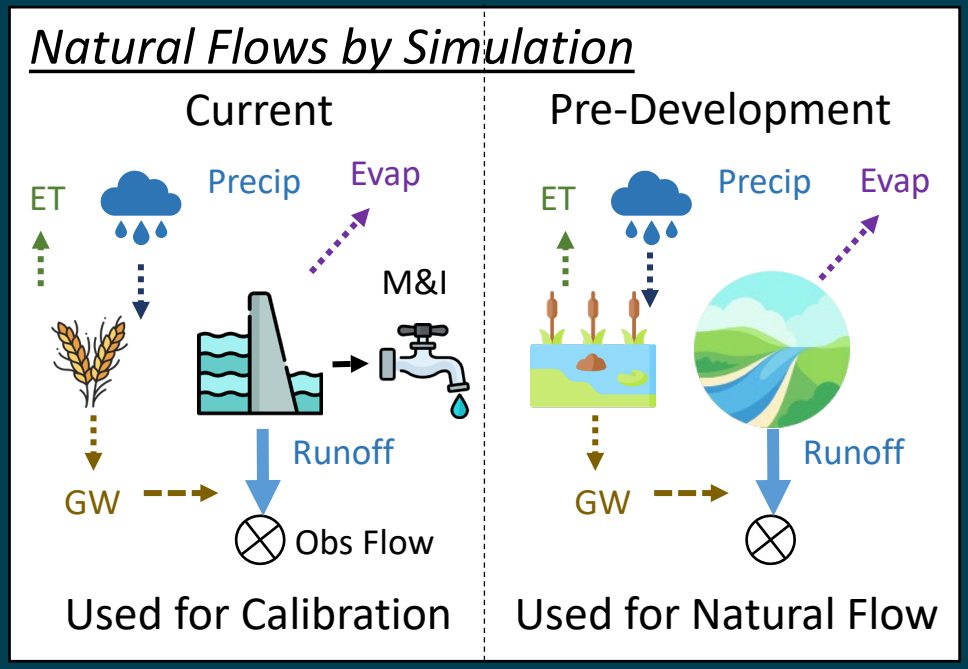
Input Data

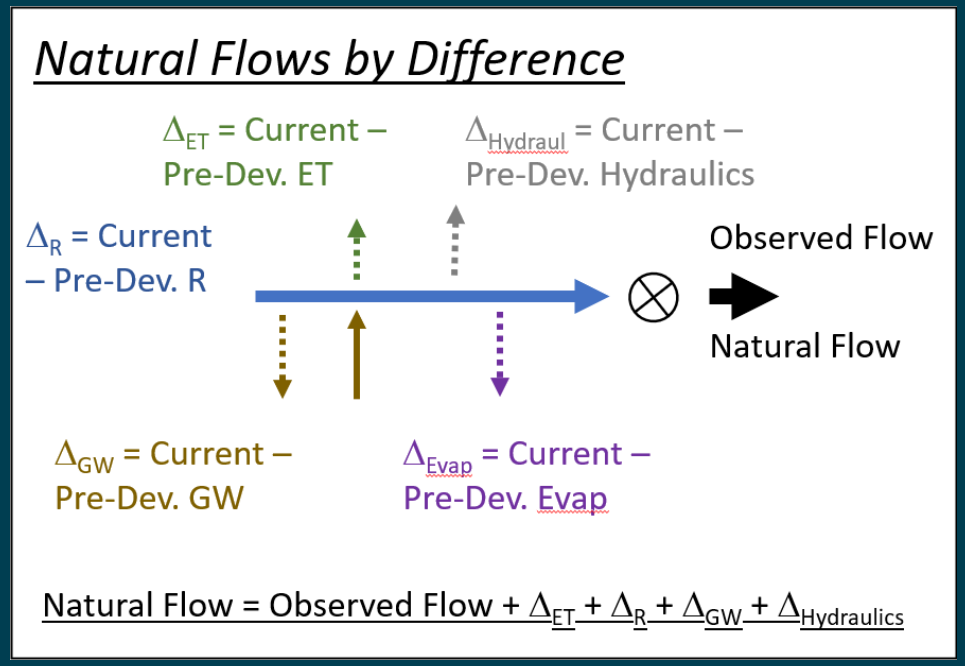
- The Mass Balance Model will combine observed flows with the modeled inflows from the complimentary models



Modeling Methodology

- This will be done primarily using two methods:
  - Natural Flow by Simulation
  - Natural Flow by Difference

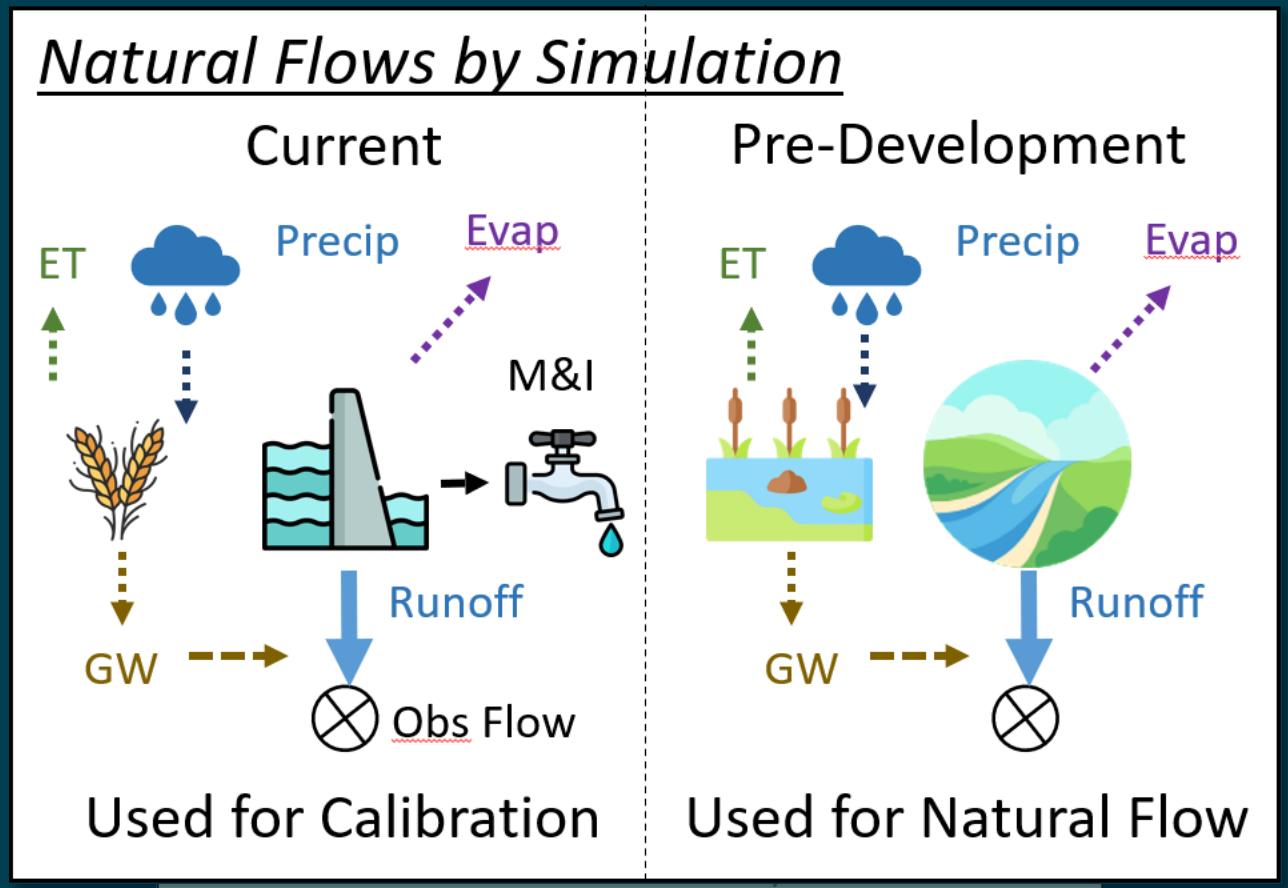


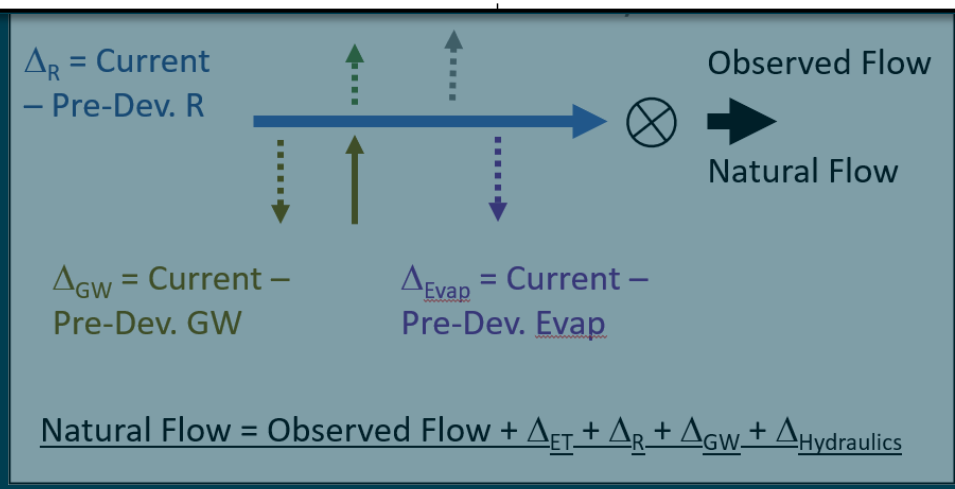


River icons created by Freepik - Flaticon

Modeling Methodology

- Natural Flows by Simulation: Calibrate the Mass Balance Model. Natural Flow estimated by removing post-project features and using pre-project simulated streamflow.

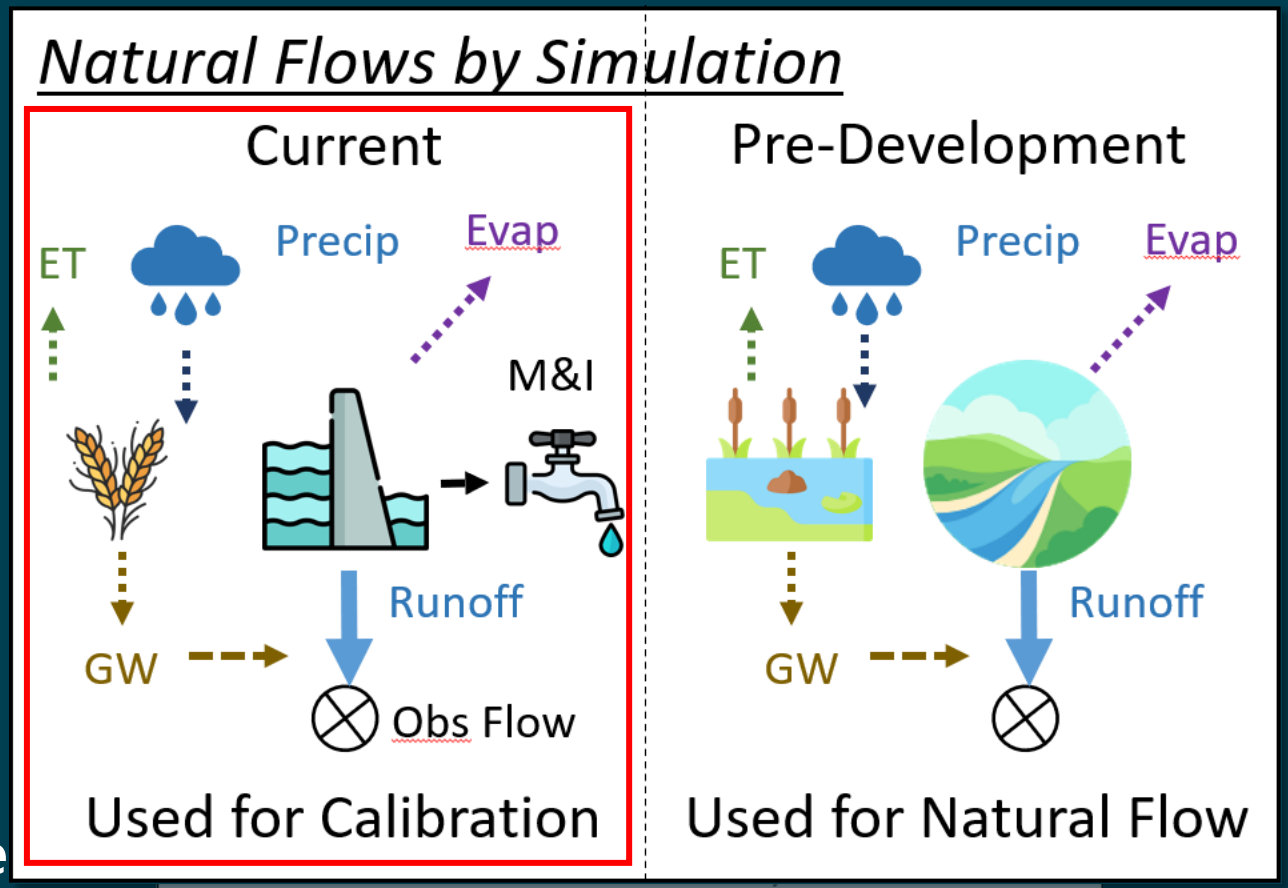


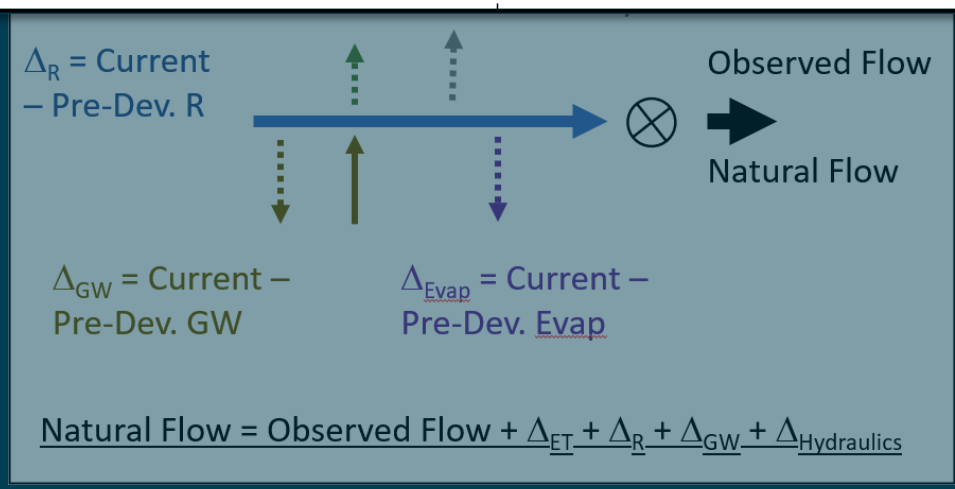


River icons created by Freepik - Flaticon

Modeling Methodology

- Example: Wood River near Klamath Agency, OR
  - Gage records available 2013-present
  - First, the Current conditions model flows would be compared to gage records from 2013-2020
  - Second, model adjustments would be made as needed to calibrate to observed records; if appropriate, similar adjustments would be made to Pre-Development mode

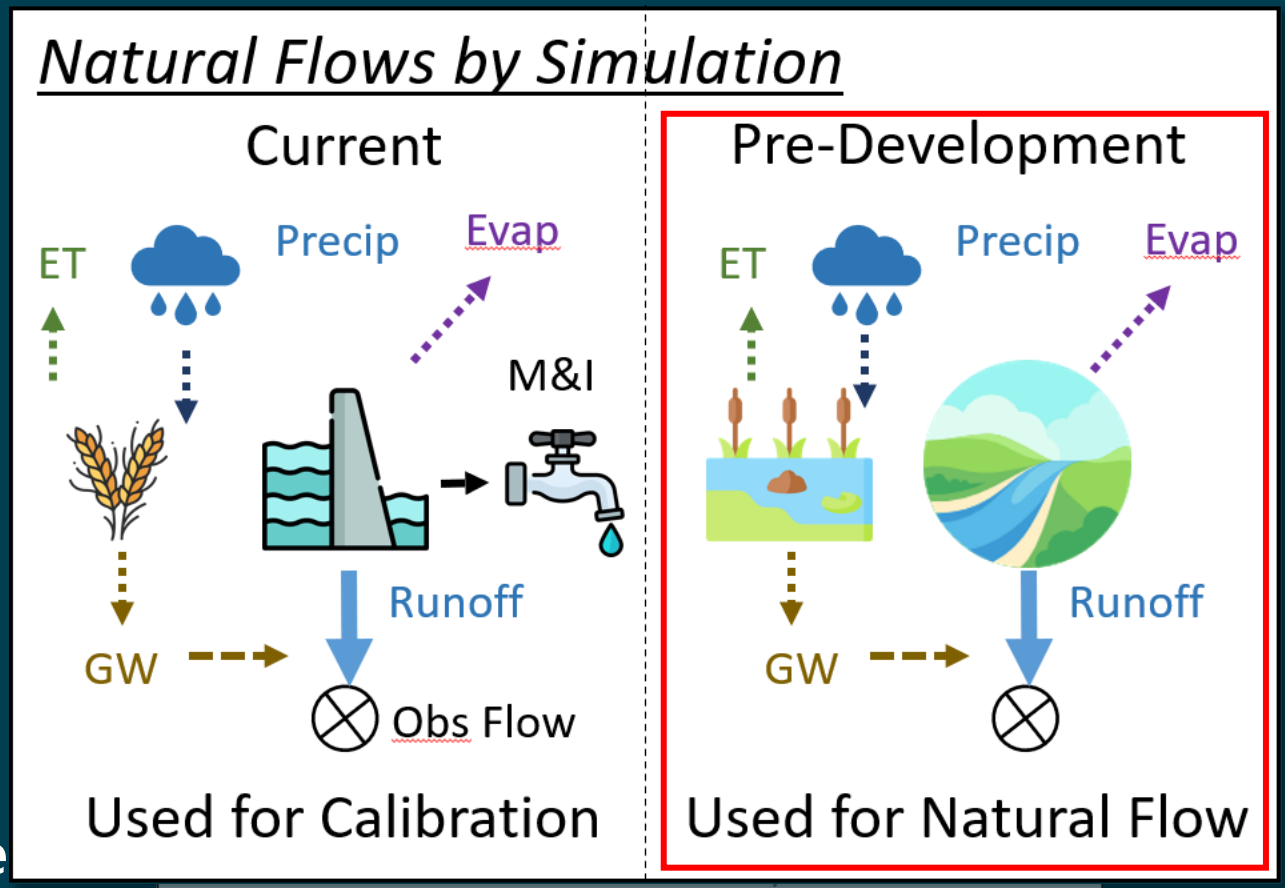


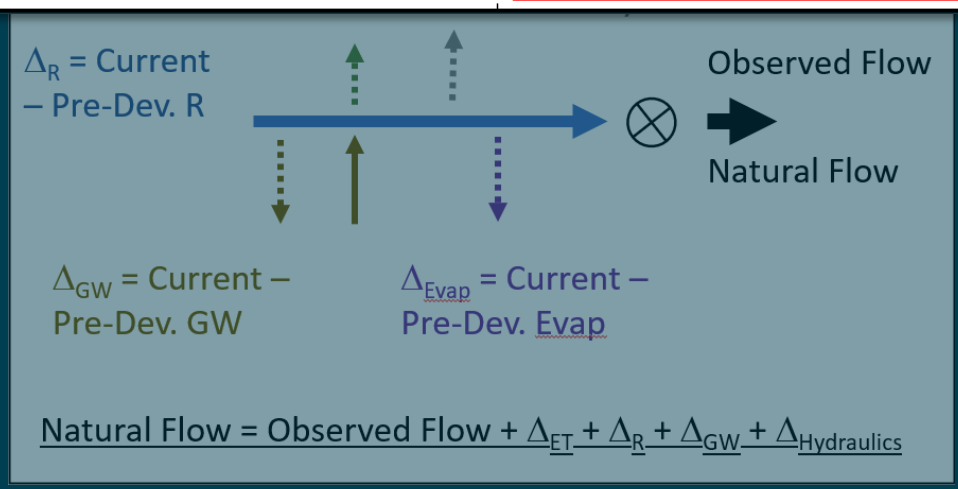


River icons created by Freepik - Flaticon

Modeling Methodology

- Example: Wood River near Klamath Agency, OR
  - Gage records available 2013-present
  - First, the Current conditions model flows would be compared to gage records from 2013-2020
  - Second, model adjustments would be made as needed to calibrate to observed records; if appropriate, similar adjustments would be made to Pre-Development model
  - Third, the Pre-Development model would then be used to estimate Natural Flow

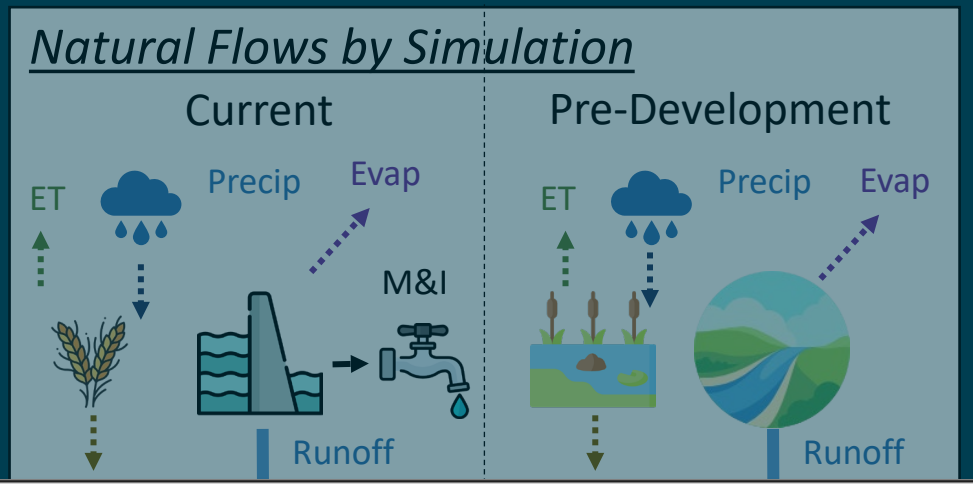




River icons created by Freepik - Flaticon

Modeling Methodology

- Natural Flows by Difference: Calculate the differences between applicable inflows to (or losses from) the Klamath River. Natural Flow estimated by adjusting observed streamflow by the calculated differences.



Natural Flows by Difference

Δ_{ET} = Current – Pre-Dev. ET

$\Delta_{Hydraul}$ = Current – Pre-Dev. Hydraulics

Δ_{R} = Current – Pre-Dev. R

Observed Flow

Natural Flow

Δ_{GW} = Current – Pre-Dev. GW

Δ_{Evap} = Current – Pre-Dev. Evap

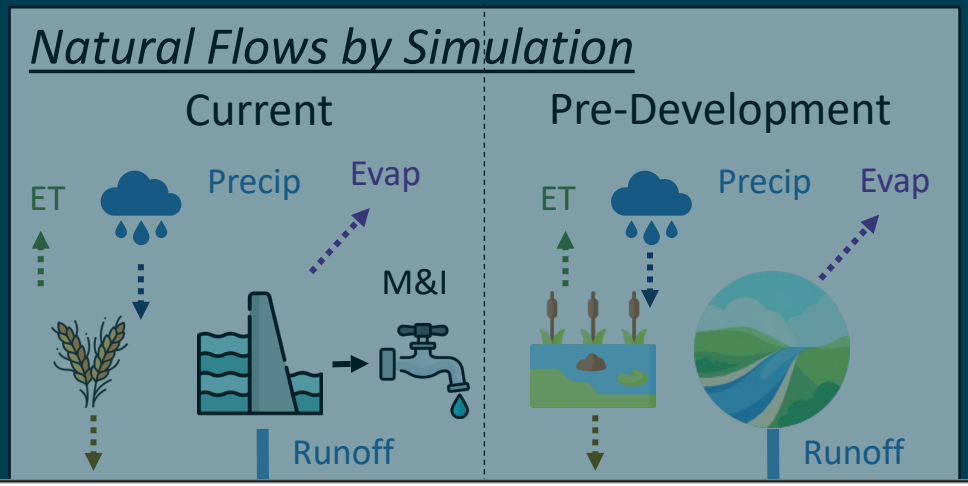
Depletions/Gains *Regulation*

$$\text{Natural Flow} = \text{Observed Flow} + \Delta_{ET} + \Delta_{R} + \Delta_{GW} + \Delta_{Hydraulics}$$

River icons created by Freepik - Flaticon

Modeling Methodology

- Example: Sprague River near Chiloquin, OR
  - Long gage records are available
  - First, observed flow would be use as the baseline for estimating natural flow
  - Second, the differences of major fluxes between Current conditions and Pre-Development conditions will be used to estimate Natural Flow from estimated flow.
  - When possible, observations and measured data will be favored over modeled data



Natural Flows by Difference

Δ_{ET} = Current – Pre-Dev. ET

$\Delta_{Hydraul}$ = Current – Pre-Dev. Hydraulics

Δ_{R} = Current – Pre-Dev. R

Observed Flow

Natural Flow

Δ_{GW} = Current – Pre-Dev. GW

Δ_{Evap} = Current – Pre-Dev. Evap

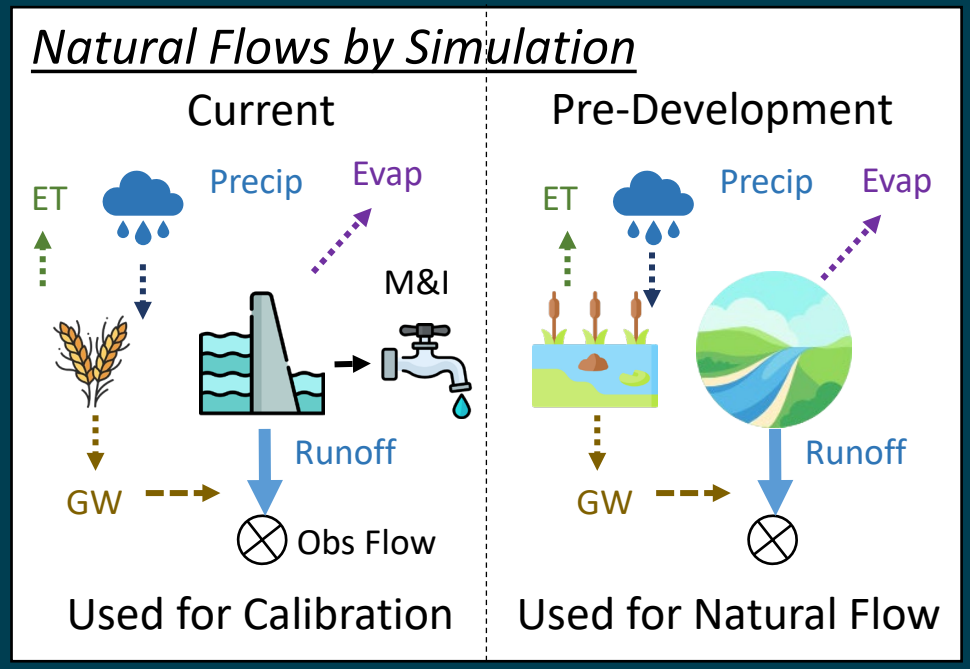
Depletions/Gains *Regulation*

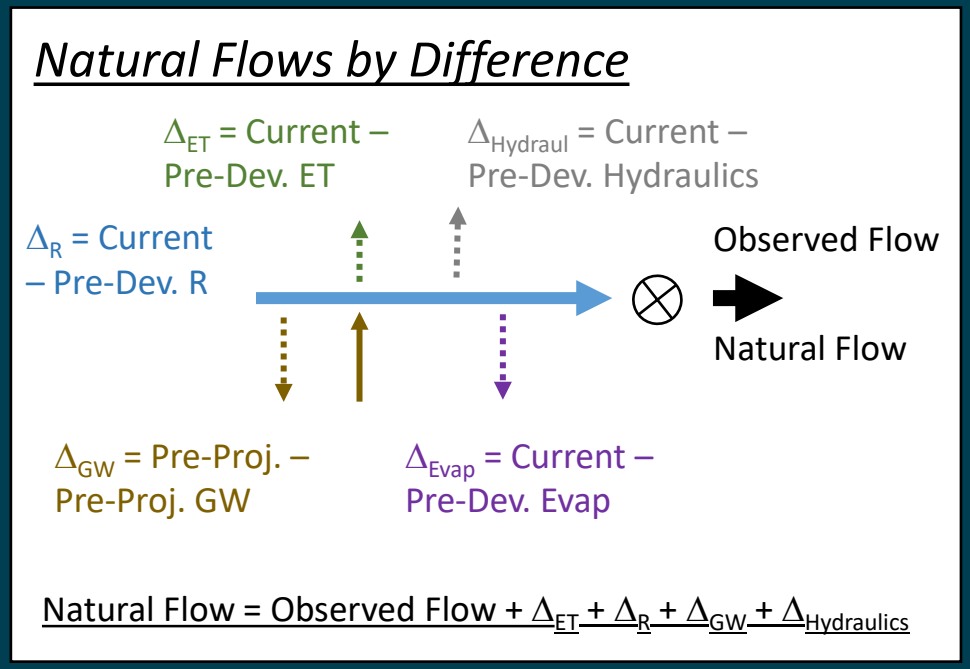
$$\text{Natural Flow} = \text{Observed Flow} + \Delta_{ET} + \Delta_{R} + \Delta_{GW} + \Delta_{Hydraulics}$$

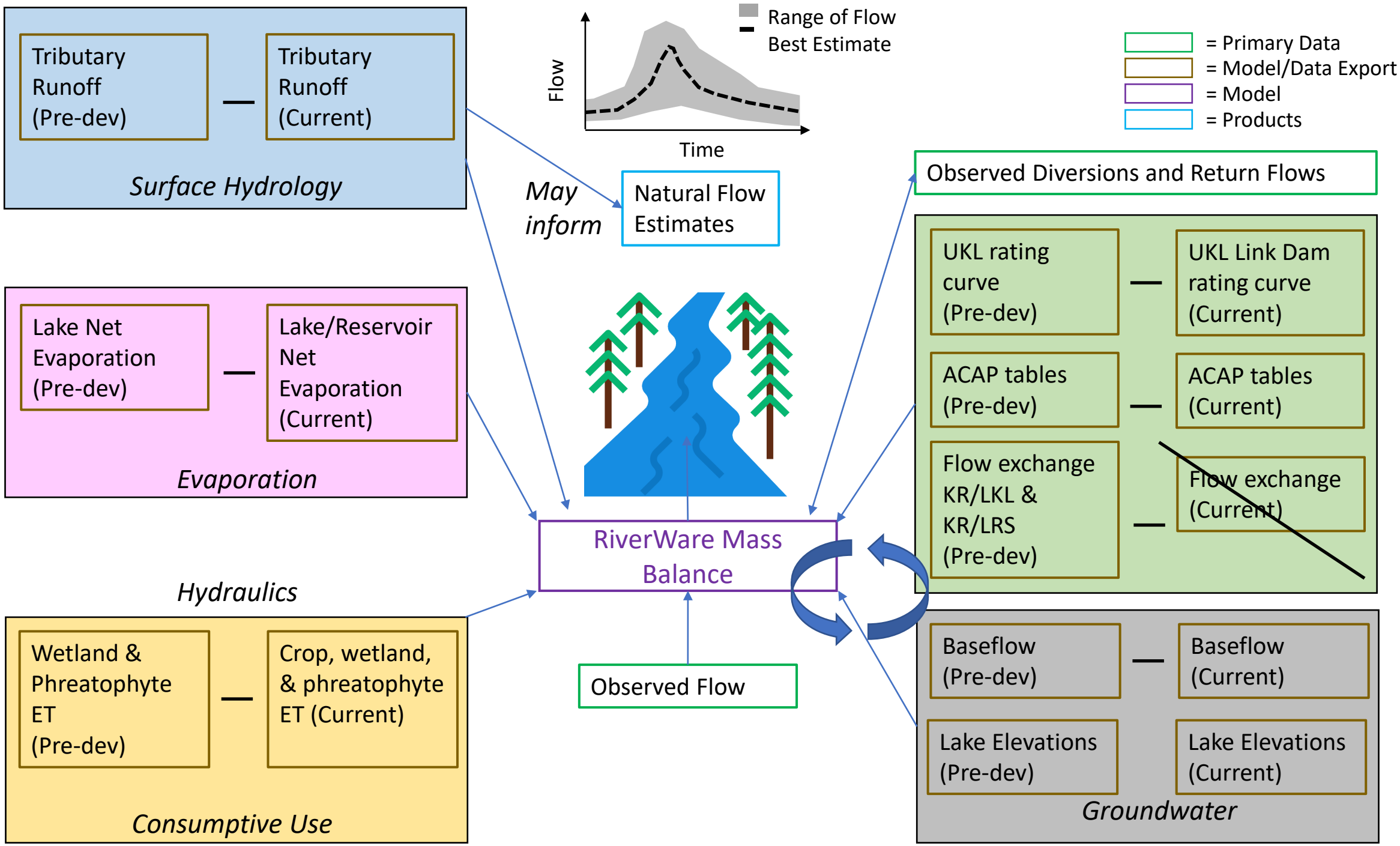
River icons created by Freepik - Flaticon

Model Calibration

- Each of the individual process models (e.g., Surface Runoff) will rely on the calibrations conducted for each process model
- In some cases, verifications of Current Condition Mass Balance results will be conducted using available gage records






Tributary Runoff (Pre-dev)
Tributary Runoff (Current)
Surface Hydrology
Range of Flow
Best Estimate
Flow
Time
= Primary Data
= Model/Data Export
= Model
= Products
May inform
Natural Flow Estimates
Observed Diversions and Return Flows
Lake Net Evaporation (Pre-dev)
Lake/Reservoir Net Evaporation (Current)
Evaporation
UKL rating curve (Pre-dev)
UKL Link Dam rating curve (Current)
ACAP tables (Pre-dev)
ACAP tables (Current)
Flow exchange KR/LKL & KR/LRS (Pre-dev)
Flow exchange (Current)
RiverWare Mass Balance
Hydraulics
Wetland & Phreatophyte ET (Pre-dev)
Crop, wetland, & phreatophyte ET (Current)
Consumptive Use
Observed Flow
Baseflow (Pre-dev)
Baseflow (Current)
Lake Elevations (Pre-dev)
Lake Elevations (Current)
Groundwater

Comparison to 2005 Natural Flow Study

2005 Study

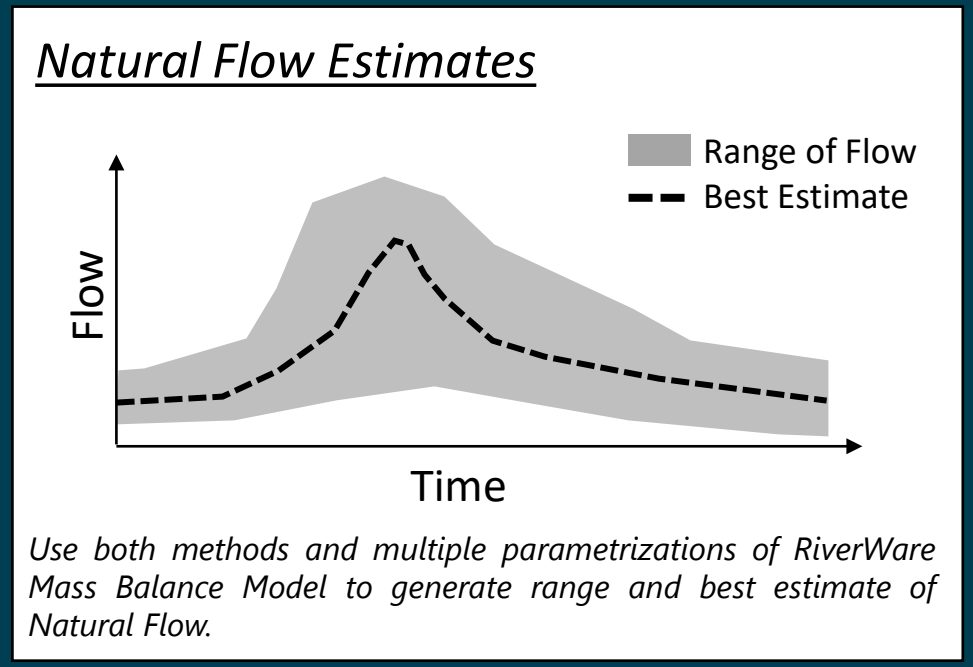
- Developed with MS Excel
- Monthly Timestep
- Lumped approach, without direct modeling of physical processes or consumptive uses
- Natural Flows upstream of Keno, only

This Study

- Developed with RiverWare
- Daily Timestep
- Distributed approach, using process models representing physical processes, development, and consumptive uses
- Natural Flows for Locations in Klamath River Basin from Sprague River to the Trinity River confluence

Natural Flow Representation

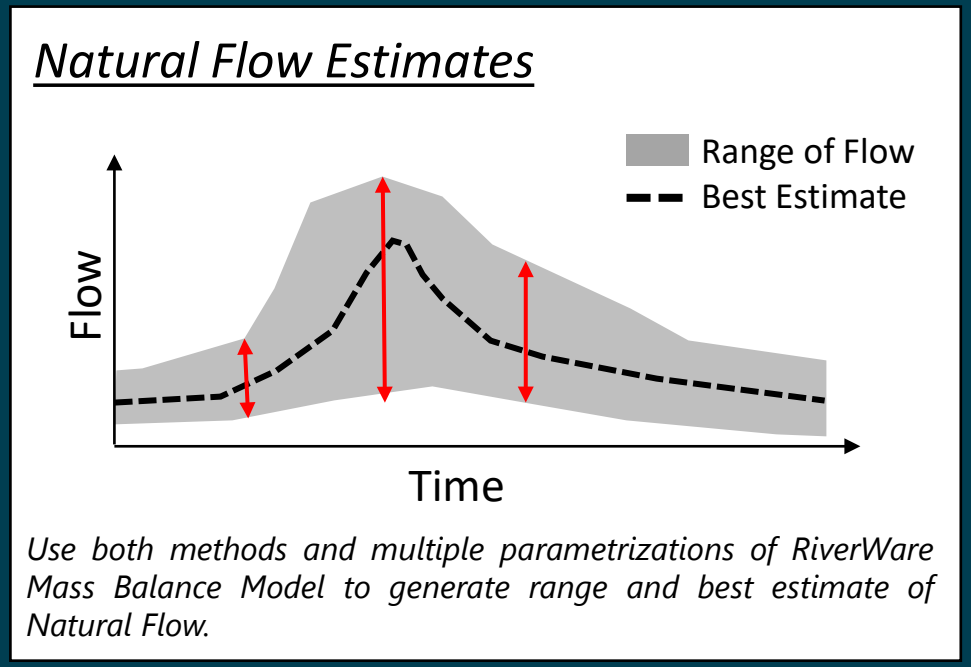
- The model is run using multiple combinations of inputs from process model simulations and parameterizations of the Mass Balance model, resulting in an ensemble of daily natural streamflow estimates at desired locations.
- Ensemble mean/median natural streamflow and uncertainty bounds will be provided in the final natural flow dataset.



Use both methods and multiple parametrizations of RiverWare Mass Balance Model to generate range and best estimate of Natural Flow.

Sensitivity & Uncertainty Analysis

- Using multiple combinations of inputs from process model simulations and parameterizations of the Mass Balance model will result in uncertainty bounds for natural flow estimates



Summary

- Uses the RiverWare model to simulate Mass Balance
  - Datasets include input from all other process models
  - Calibration to existing conditions when simulations and observations allowed
- Improves upon the 2005 Study by:
  - Using a widely accepted mass balance model, RiverWare
  - Reducing timestep to daily, from monthly
  - Including additional locations and modeled inputs
- Represents Natural flow by:
  - Using process model simulation results under pre-development conditions

    AND
  - Using the difference between current and pre-development conditions process model simulation results

Questions and Additional Discussion

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Tim Clarkin
tclarkin@usbr.gov

BUREAU OF RECLAMATION