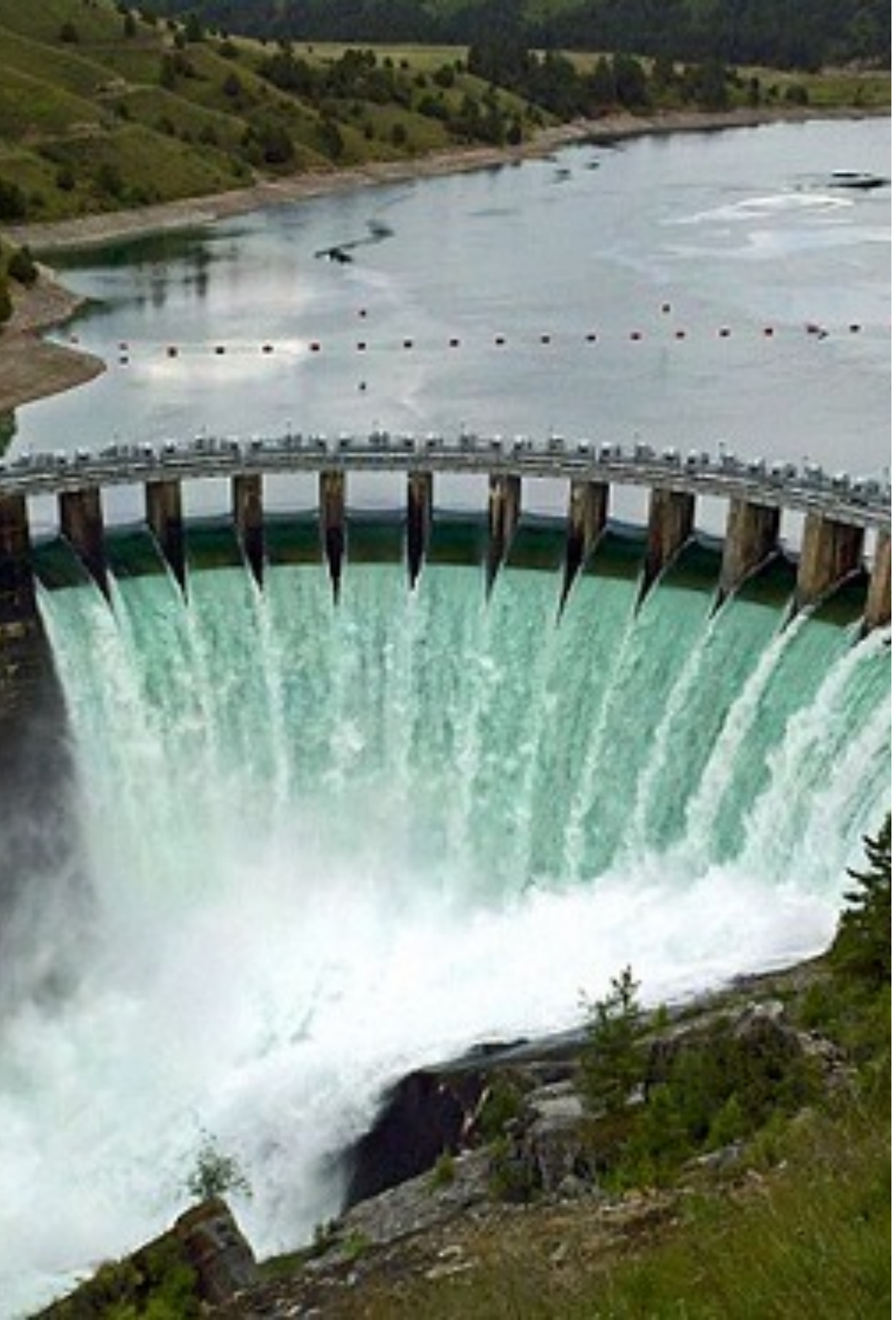

Integrating Water Quality Objectives into Reservoir Operations Simulations

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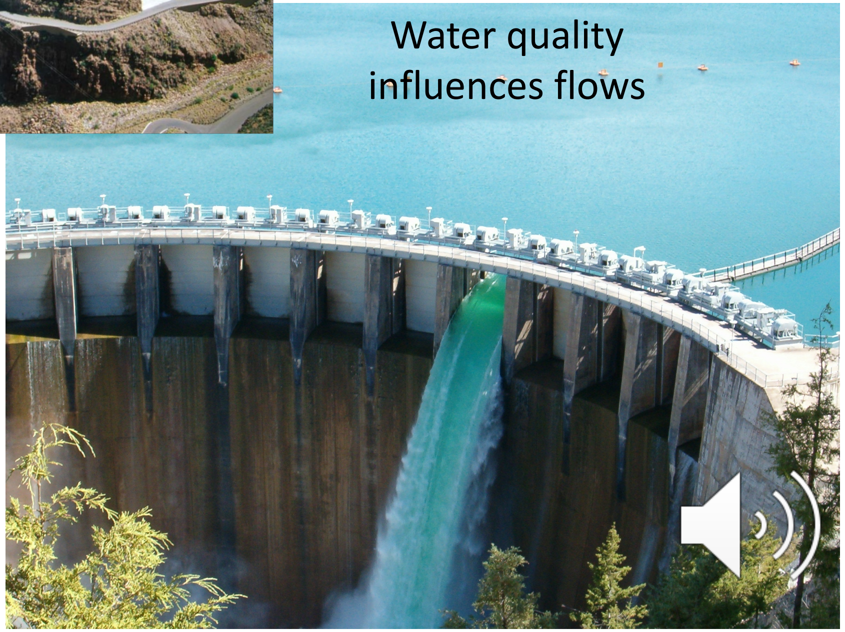
AGU Fall Meeting 2021

ERDC

Project Purpose

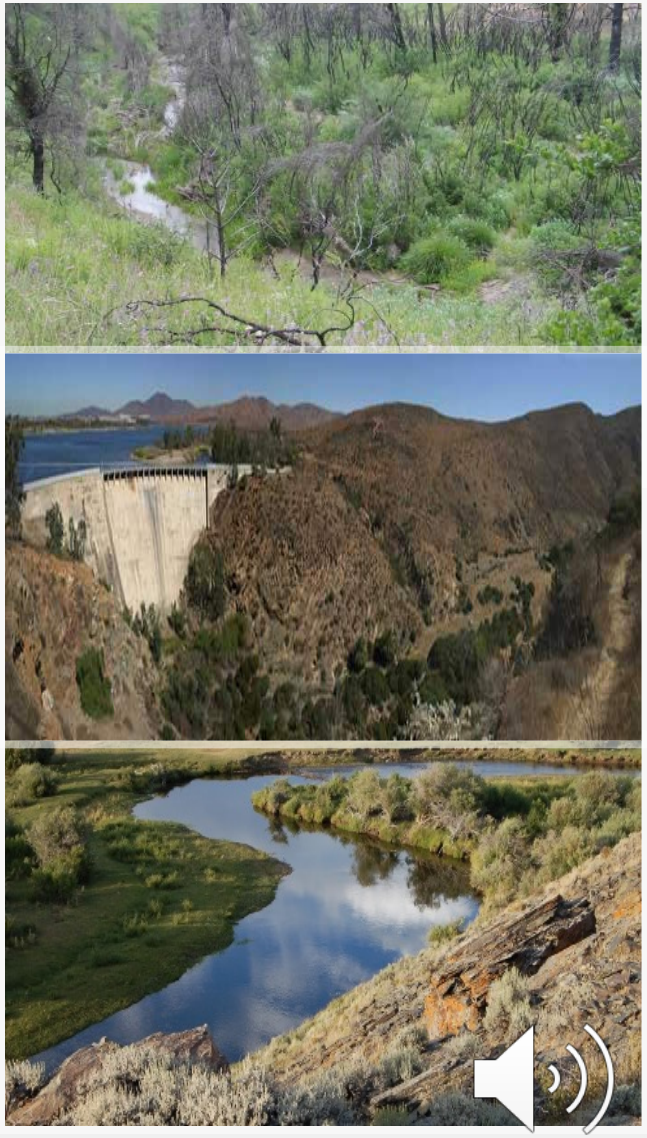
- Need
  - Reservoir operations simulation software capable of integrating environmental objectives into reservoir release decisions
- Purpose
  - Integrate water quality modeling capabilities into HEC-ResSim, enabling water quality and related environmental objectives to directly inform reservoir release decision-making, while providing capabilities for watershed-scale ecosystem assessment and management

Flows influence water quality



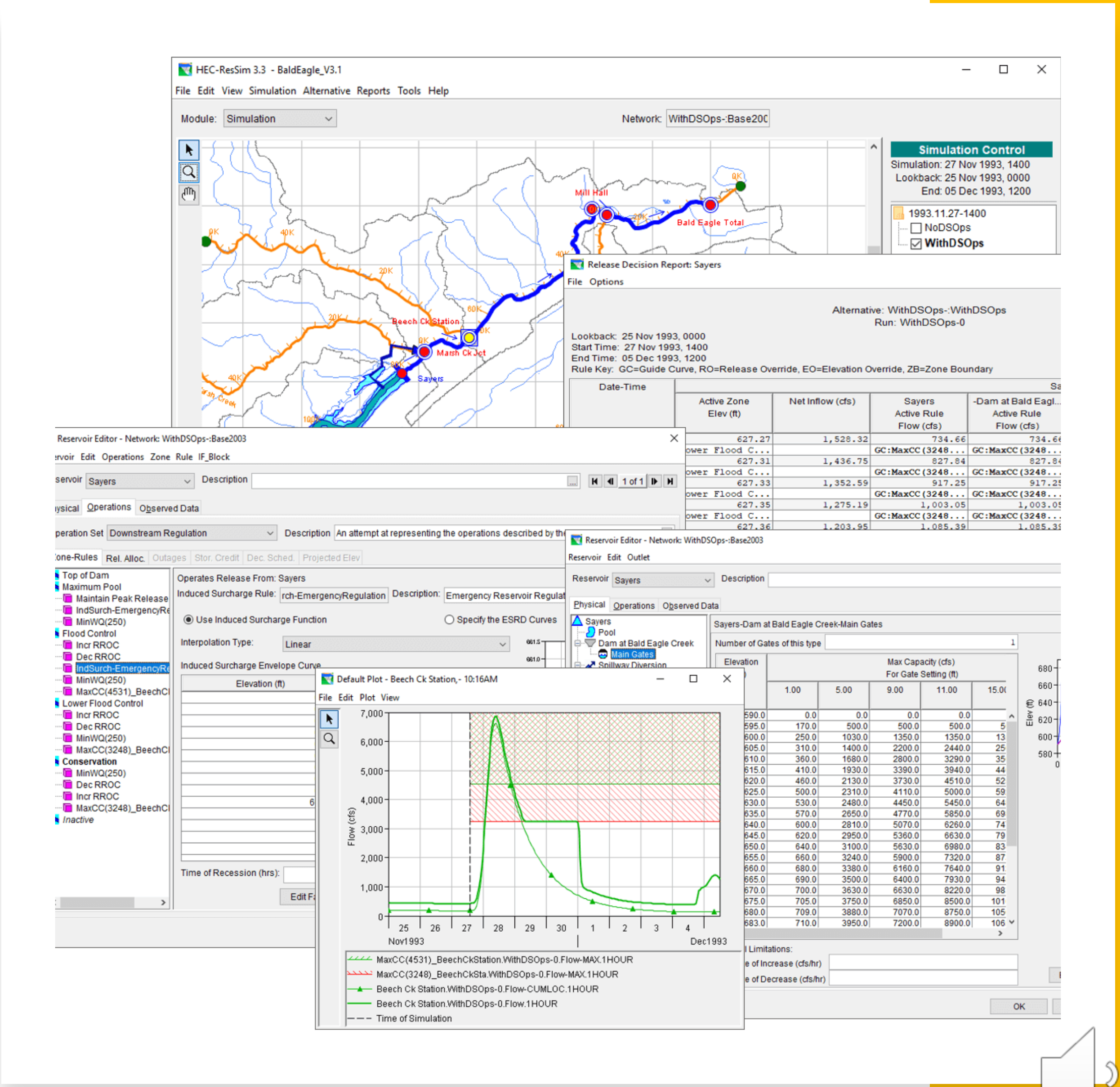
Environmental Modeling Capabilities

- An efficient and effective way to develop new water quality capabilities is to integrate them within an existing hydrologic or hydraulic (H&H) model. The U.S. Army Corps of Engineers has several widely deployed models that simulate watershed runoff, river hydraulics, and reservoir operations. Our team at USACE-ERDC has developed a modular library of environmental modeling capabilities.
- ClearWater (Corps Library for Environmental Analysis and Restoration of Watersheds) provides environmental simulation capabilities that are designed to leverage existing hydrologic and hydraulic (H&H) models.
- Water quality kinetics and vegetation simulation modules
    - NSM: Nutrient Simulation Module (NSM-I and NSM-II)
    - TSM: Temperature Simulation Module
    - GSM: General Constituent Simulation Module
    - CSM: Contaminant Simulation Module
    - MSM: Mercury Simulation Module
    - SSM: Solids Simulation Module
    - RVSM: Riparian Vegetation Simulation Module
- A water quality engine that computes the transport (advection and diffusion) of heat and mass across the watershed
- Data visualization and reporting capabilities
- A water quality framework that integrates the water quality modules, water quality engine, existing H&H models, initial and boundary condition data, output data, and user interface to form a comprehensive, integrated, adaptable, and customizable environmental modeling and analysis system.



Approach

- Develop fully integrated water quality capabilities into HEC-ResSim (Reservoir System Simulation)
- HEC-ResSim simulates reservoir operations at one or more reservoirs for
  - Flood management
  - Low flow augmentation
  - Water supply
- Applications:
  - Planning studies
  - Detailed reservoir regulation plan investigations
  - Real-time decision support



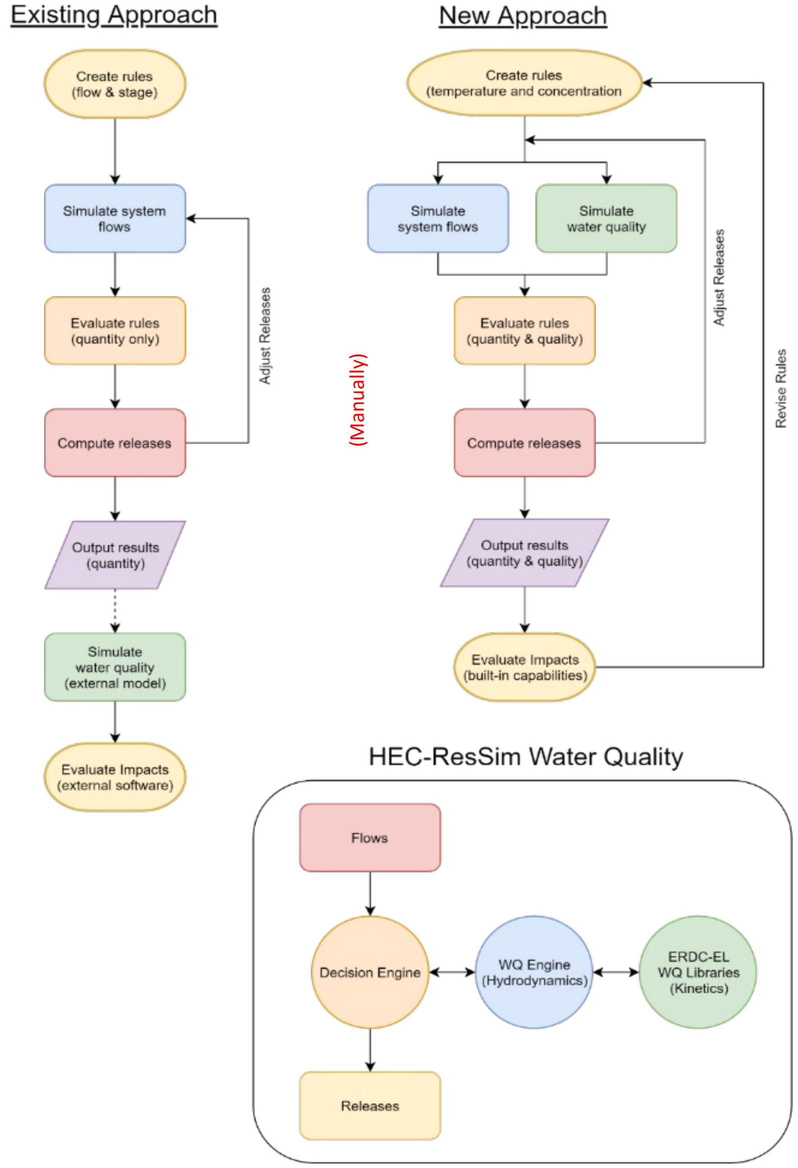
Benefits

- HEC-ResSim is a widely deployed reservoir operations modeling program.
  - Users can compare multiple alternatives for planning studies.
  - ResSim is a critical part of the U.S. Army Corps of Engineers’ Corps Water Management System (CWMS) for real-time operation decision-making.
- Impacts Assessment
  - Integrated WQ capabilities and graphics allow rapid, efficient, and effective environmental impacts assessment.
- Environmental Flows
  - Users can create reservoir operation rules based on temperatures and constituent concentrations.
  - Rules based on flow or stage can be used in conjunction with WQ rules for ecosystem restoration and management (E-flows).
- Selective withdrawal supports reservoirs with selective withdrawal structures.

Integrating Water Quality in Reservoir Release Decision-Making

Typical Modeling Strategy:

- WQ is simulated after computing the hydrology and release decisions.
- WQ operation rules are specified indirectly (using stage and flow) to meet environmental objectives.
- Environmental objectives are often combined with other objectives, like navigation, flood control, or hydropower.
- If the desired environmental benefits of an alternative are not achieved, new guesses need to be made, and the simulation recomputed. This stage is often skipped altogether.



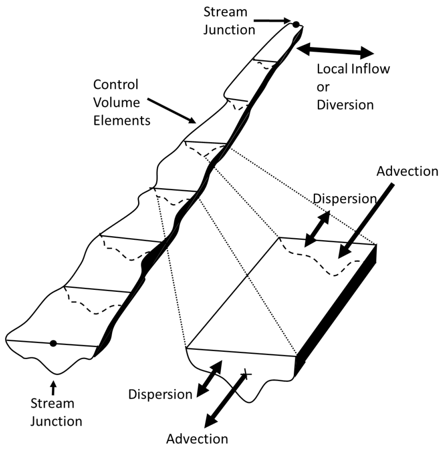
New Capabilities:

- WQ is simulated in parallel with the hydrology and release decisions.
- WQ operation rules can be specified directly (temperature, concentration, or load) to meet environmental objectives.
- Environmental objectives can be specified and managed independently of other objectives, clarifying the environmental impacts of operation decisions.

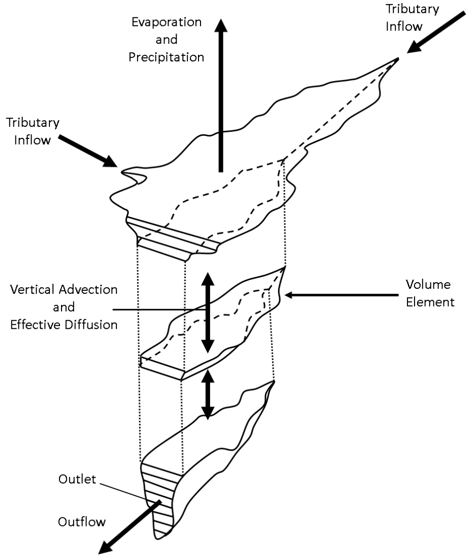
Water Quality Transport Engine

$$\underbrace{\frac{\partial C}{\partial t}}_{\text{time derivative}} + \underbrace{\frac{\partial (vC)}{\partial x}}_{\text{advection}} = \underbrace{\frac{\partial}{\partial x}\left(K\frac{\partial c}{dx}\right)}_{\text{diffusion}} + \textbf{sources/sinks} \qquad \textit{(1D)}$$

- Finite Volume Numerical Scheme
  - 1D river reach with junctions
  - 1D vertically stratified reservoir
- Explicit solution scheme with sub-stepping
- Cell face concentrations determined with 1st order upwind method; 2nd order flux-limiting method in testing.
- Accept flows computed by hydraulic or hydrologic routing



1D Reach

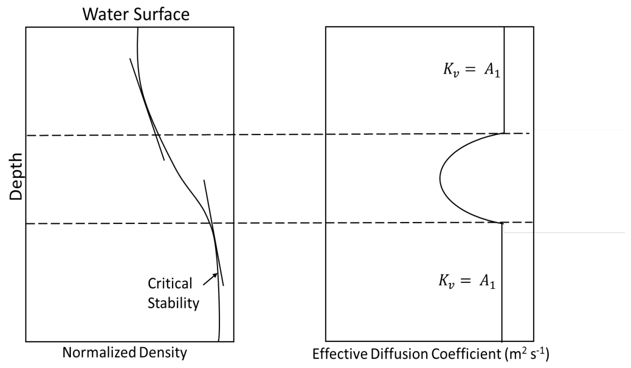


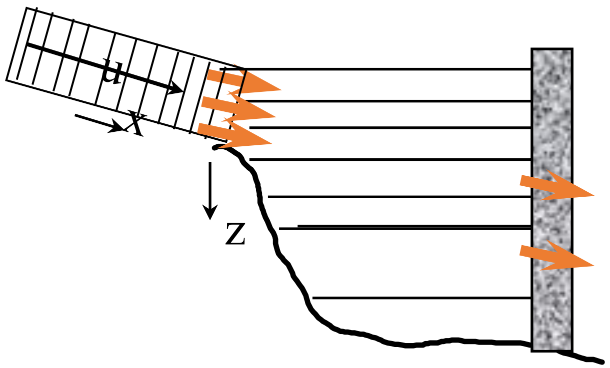
1D Reservoir

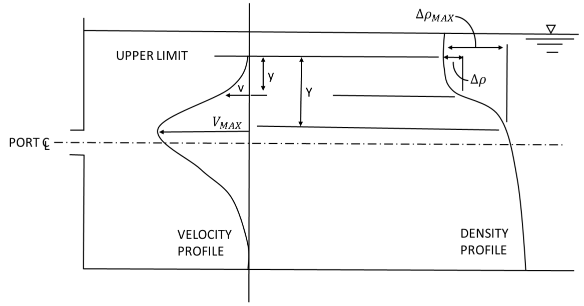
RMA, "Generalized One-Dimensional Reservoir and River Water Quality Engine Prototype", prepared for the USACE Hydrologic Engineering Center, November 2017

Density-Stratified Reservoir Simulations

- Vertical Diffusion and Mixing Layers
    - Vertical diffusion and layer stability are related to surface wind and density gradients, which are in turn functions of temperature, salinity, or suspended solids
- Inflow Allocation
    - Determine reservoir layer with density equal to inflow density.
    - If in upper or lower mixed zones (epilimnion or hypolimnion), distribute over zone.
    - If in stratified zone, determine thickness of inflow zone.
- Withdrawal Allocation
    - Layers from which water is withdrawn is a function of the outlet elevation and size, density distribution, and flow rate.
- Methodologies adapted from HEC-RAS-WQ, CE-QUAL-R1, CE-QUAL-W2, and HEC-5Q

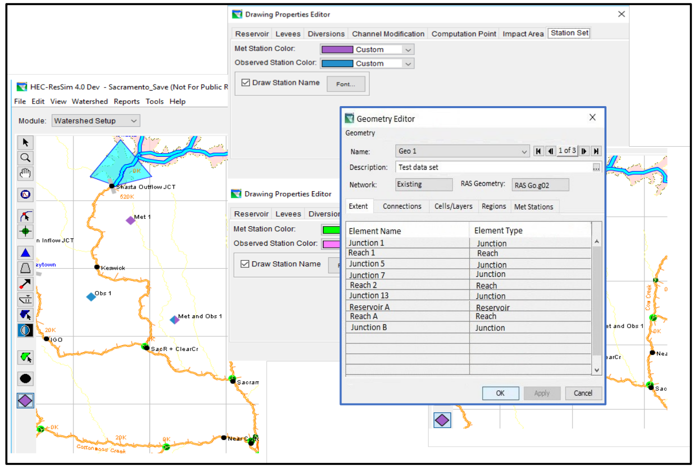




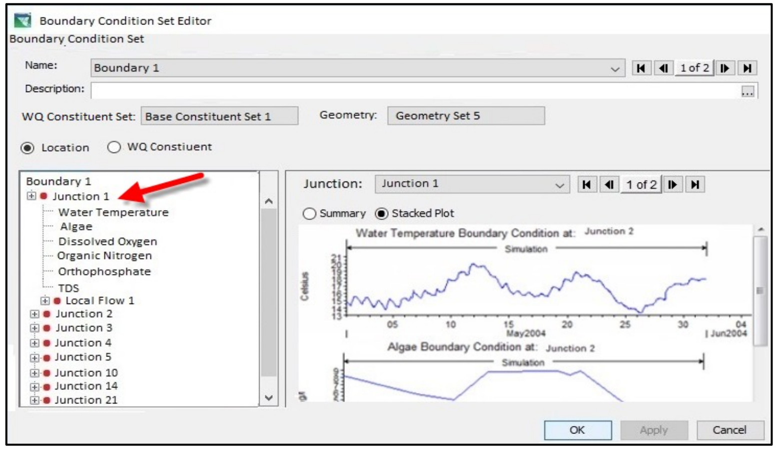


Water Quality Modeling User Interface

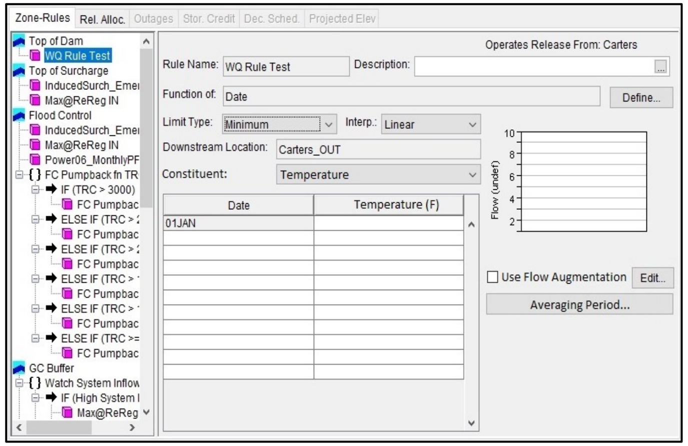
Model Geometry



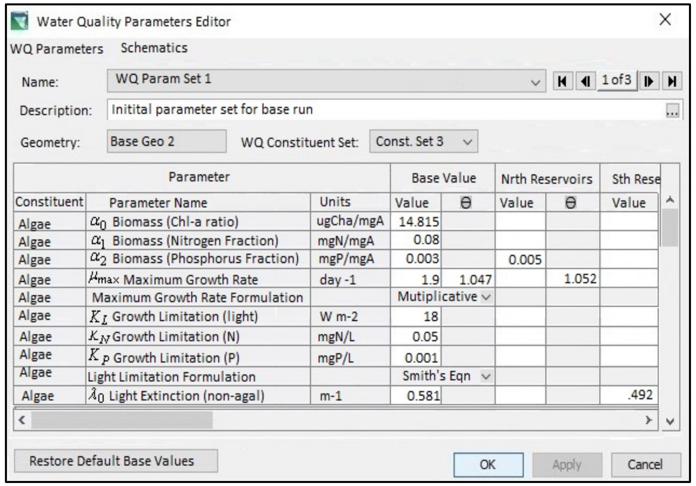
Specifying Boundary Conditions



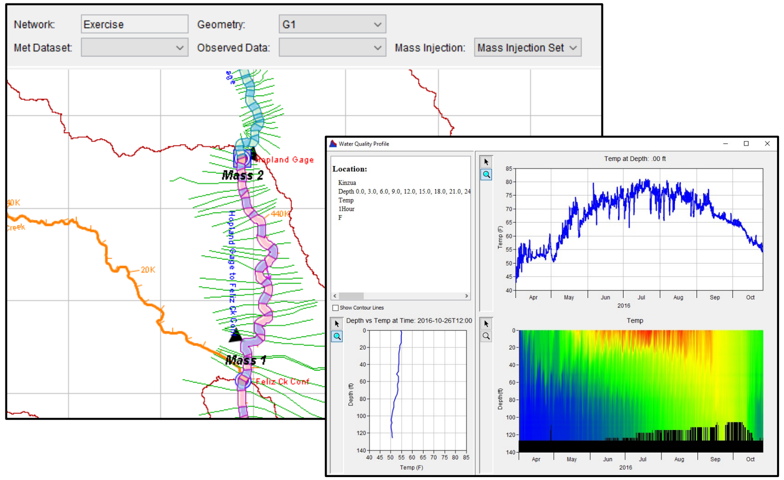
Operating Rule Priorities



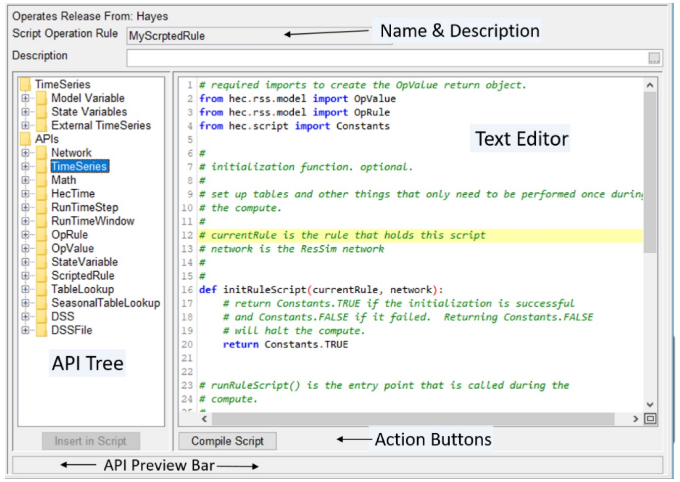
Constituent Relation Parameters



Visualization



Scripted Rules and State Variables



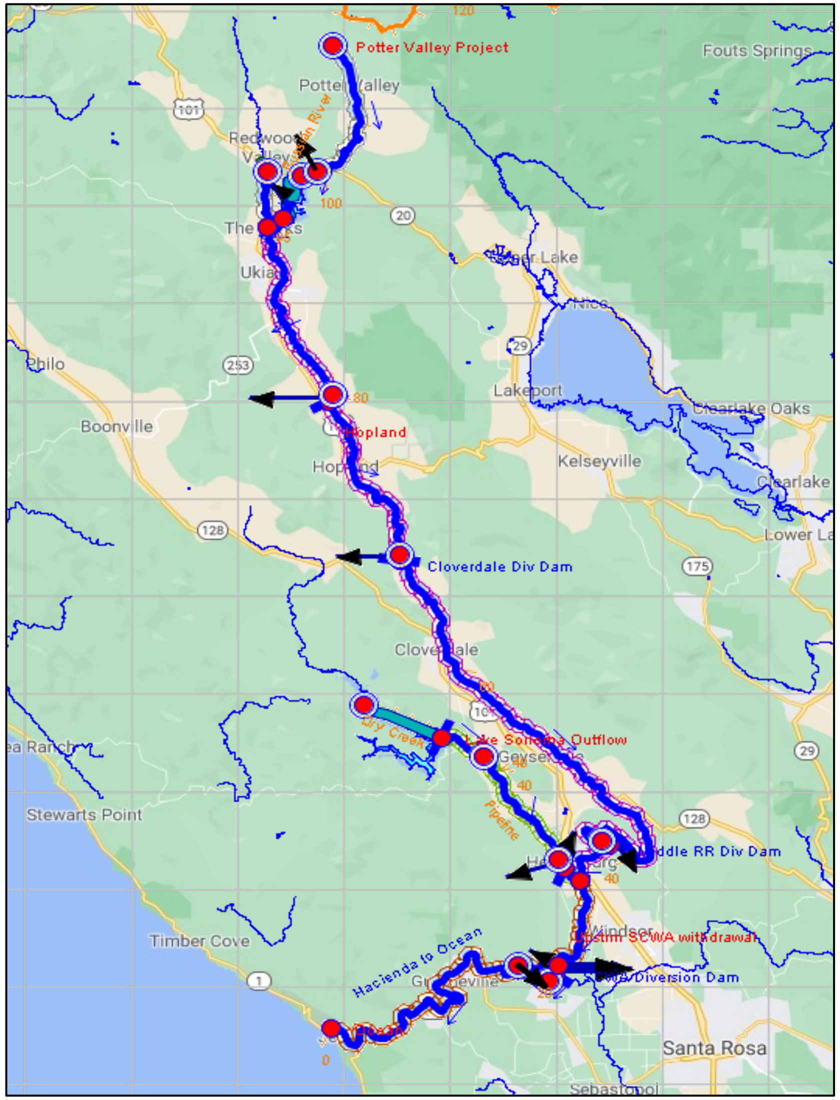
Temperature and Dissolved Oxygen Simulation with HEC-ResSim

Russian River, California

Performed by RMA for the Sonoma County Water Agency

Objective: Understanding impacts of Lake Mendocino, Lake Sonoma, and temporary diversion dams on temperature and dissolved oxygen throughout the Russian River System

- Phytoplankton has an important impact on light penetration in the reservoirs, which impacts stratification.
- Benthic algae has an important impact on diurnal variation in dissolved oxygen in the river reaches.
- HEC-ResSim WQ will be the replacement for the legacy HEC-5Q model.



Temperature and Dissolved Oxygen Simulation with HEC-ResSim

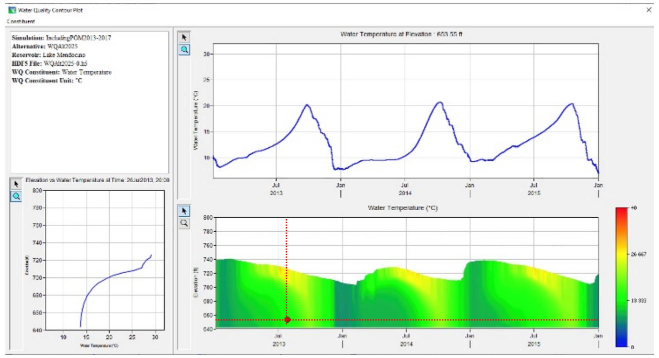
Russian River, California

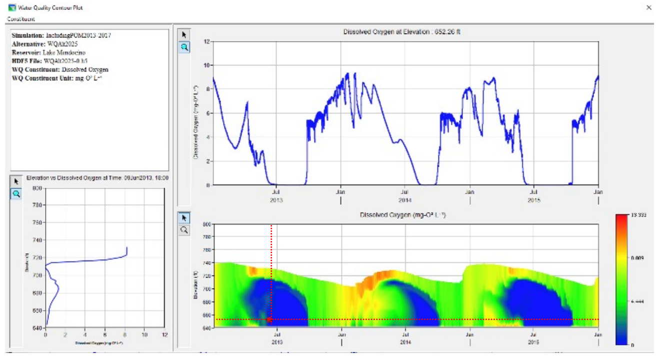
Performed by RMA for the Sonoma County Water Agency

Temperature

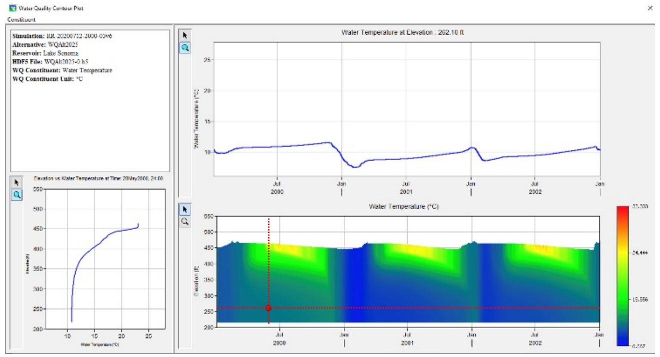
Dissolved Oxygen

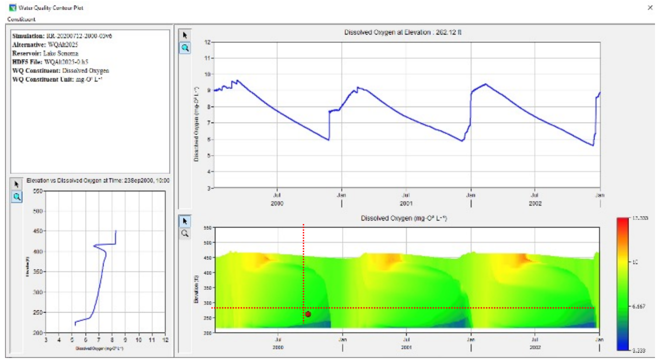
Lake Mendocino

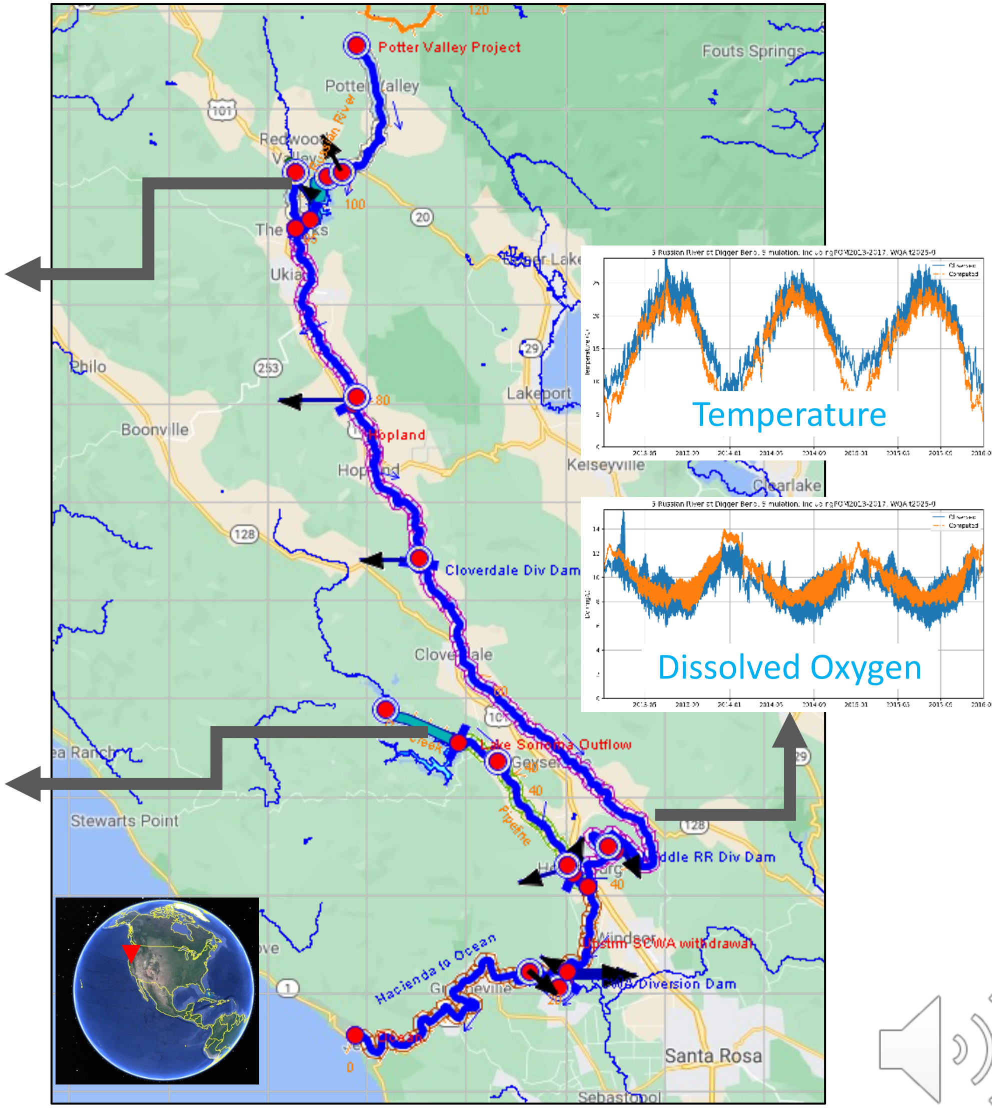




Lake Sonoma







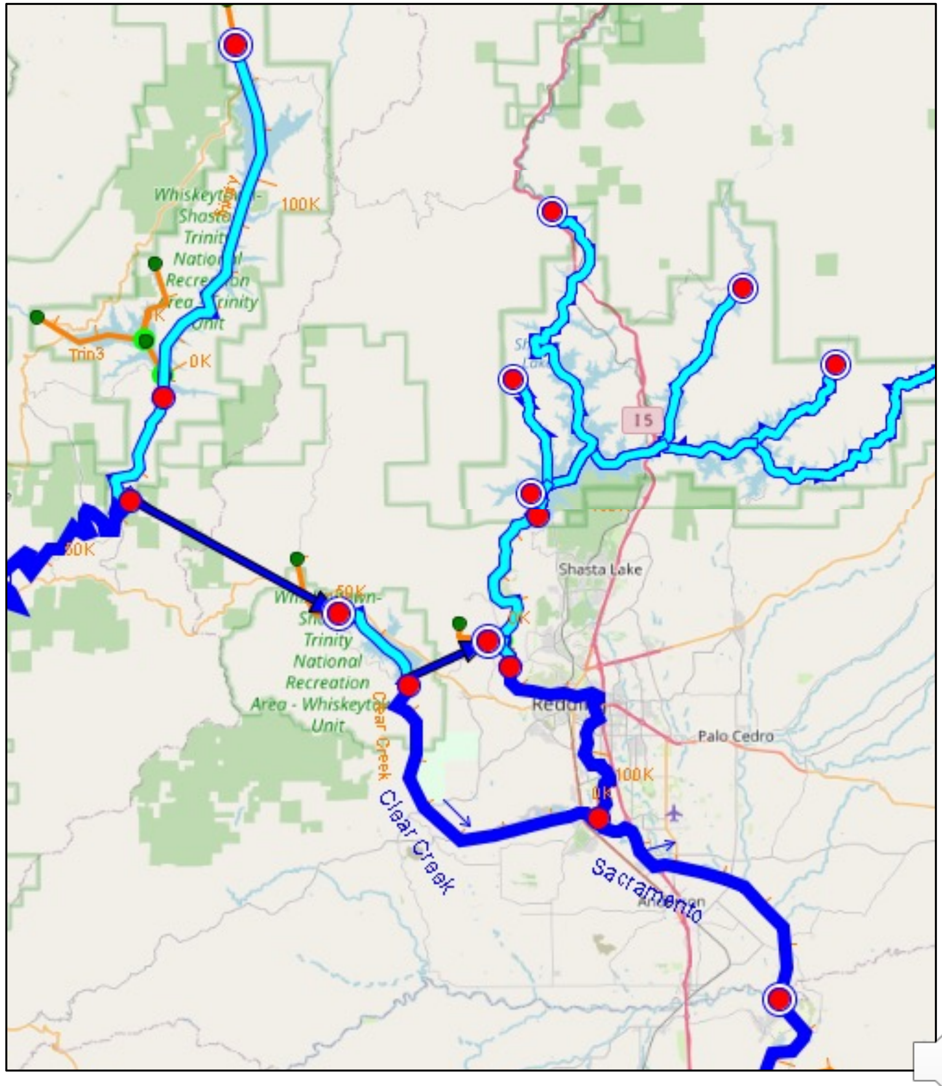
River Temperature & Cold-Water Pool Management

Upper Sacramento River

Performed by RMA for the U.S. Bureau of Reclamation

Objective: Management of river temperature in region of critical fish habitat

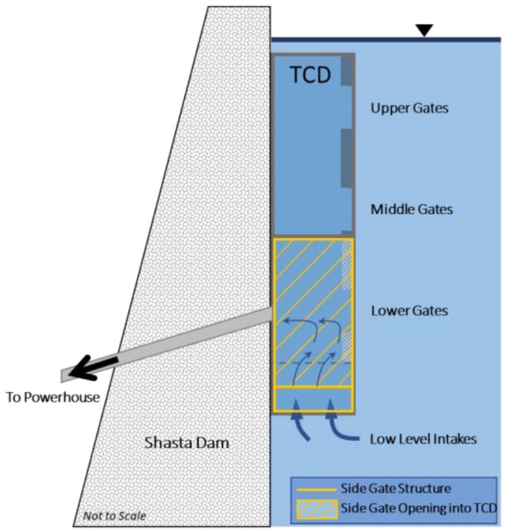
- A primary modeling objective is to establish release temperature targets for optimum cold water pool management.
- Shasta Temperature Control Device operation (TCD) is a key element of the model.
- HEC-ResSim WQ is being tested as eventual replacement for the legacy HEC-5Q model.
- The final model will include Shasta, Keswick, Trinity, Lewiston, and Whiskeytown reservoirs along with connecting river segments and tunnels.



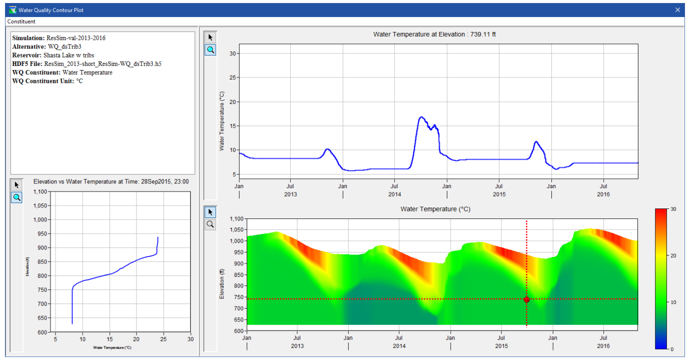
River Temperature & Cold-Water Pool Management

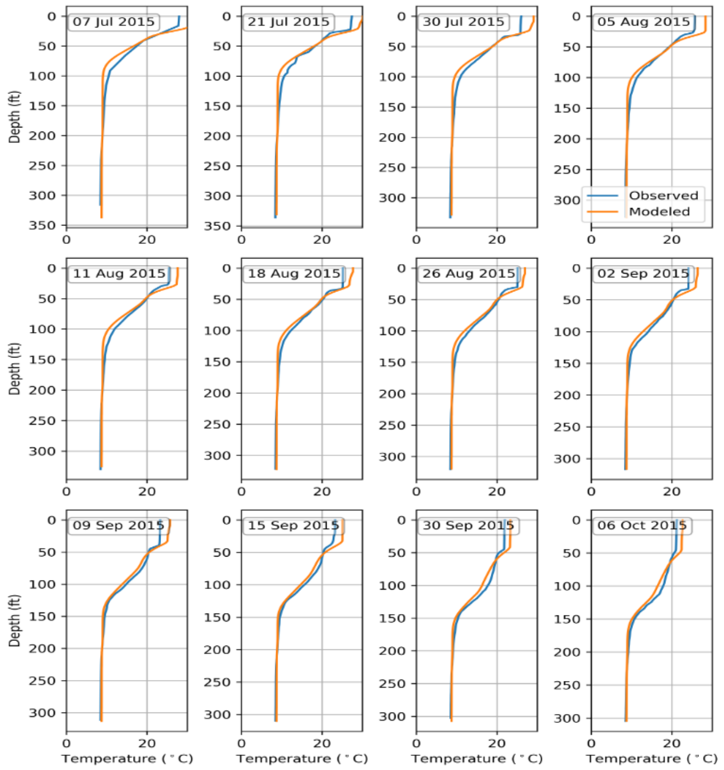
Upper Sacramento River

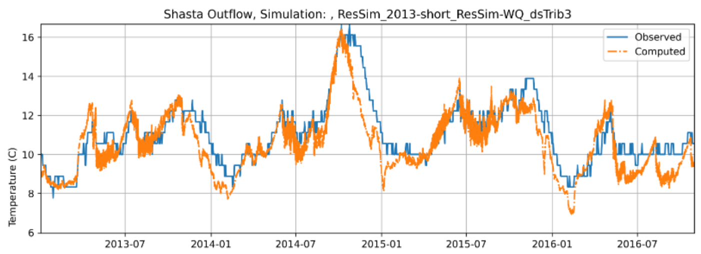
Performed by RMA for the U.S. Bureau of Reclamation

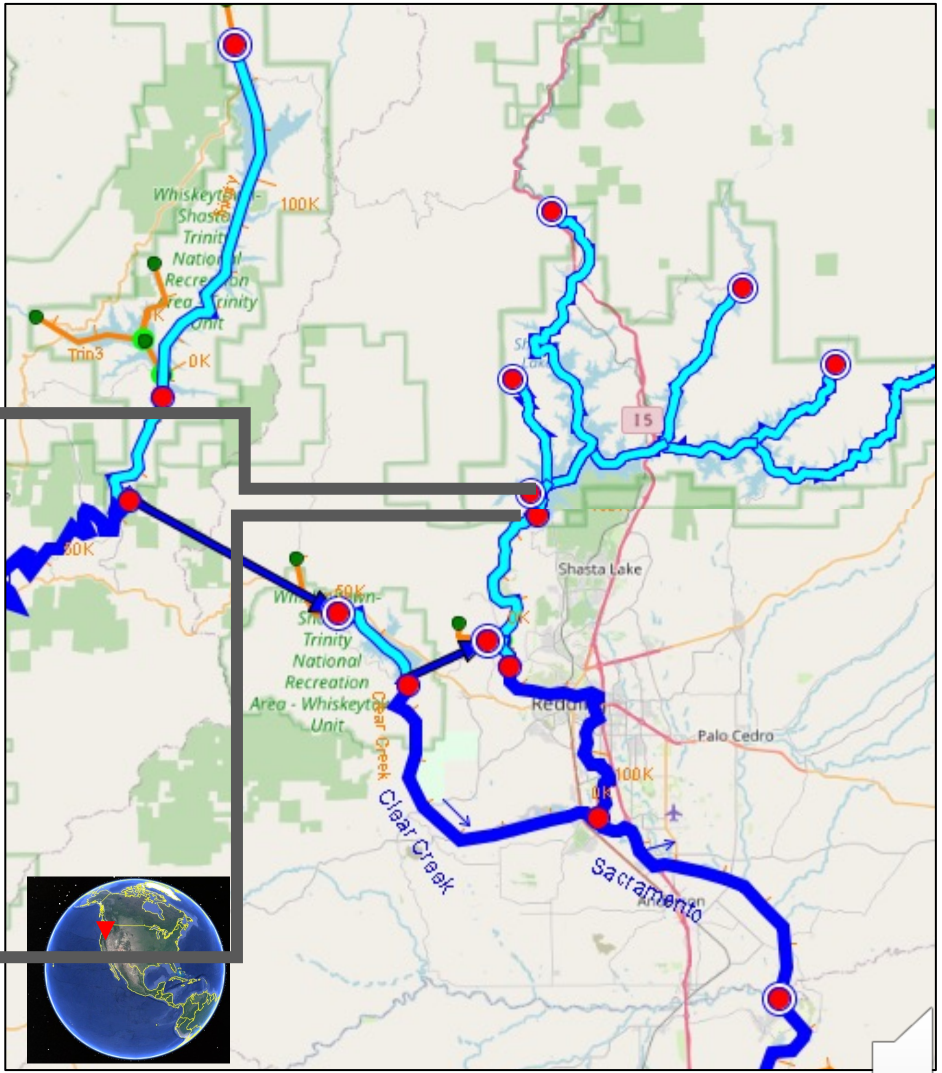


Shasta TCD graphic courtesy of Watercourse Engineering









Summary

- Water quality capabilities have been implemented in HEC-ResSim.
  - ClearWater engine and modules: temperature and eutrophication modeling capabilities
- The new capabilities integrate water quality simulations with the reservoir system release decision-making process.
- Water quality objectives can be specified in terms of temperature and concentration instead of estimated flows and depths.
- The user interface enables users to set up and configure water quality models, specify data input and output, create rules for environmental objectives, and visualize results for environmental analyses.
- HEC-ResSim is compatible with the HEC integration software packages HEC-WAT and CWMS/RTS.
- Two case studies were prepared to demonstrate some of the new WQ capabilities.
  - Temperature, nutrients, primary production, and dissolved oxygen simulation for the Russian River, CA
  - Temperature simulation for the upper Sacramento System, CA