Institute for Water Resources

Hydrologic Engineering Center

HEC Software for Environmental Analysis

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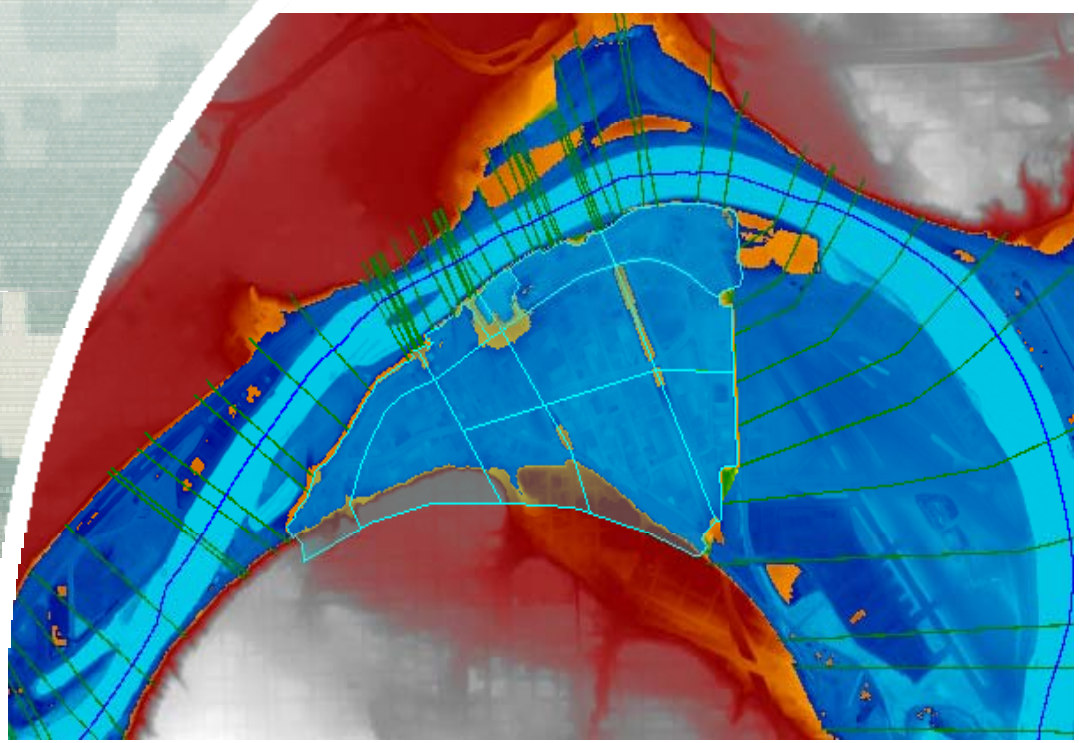
23 July 2013



US Army Corps of Engineers
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Hydrologic Engineering Center

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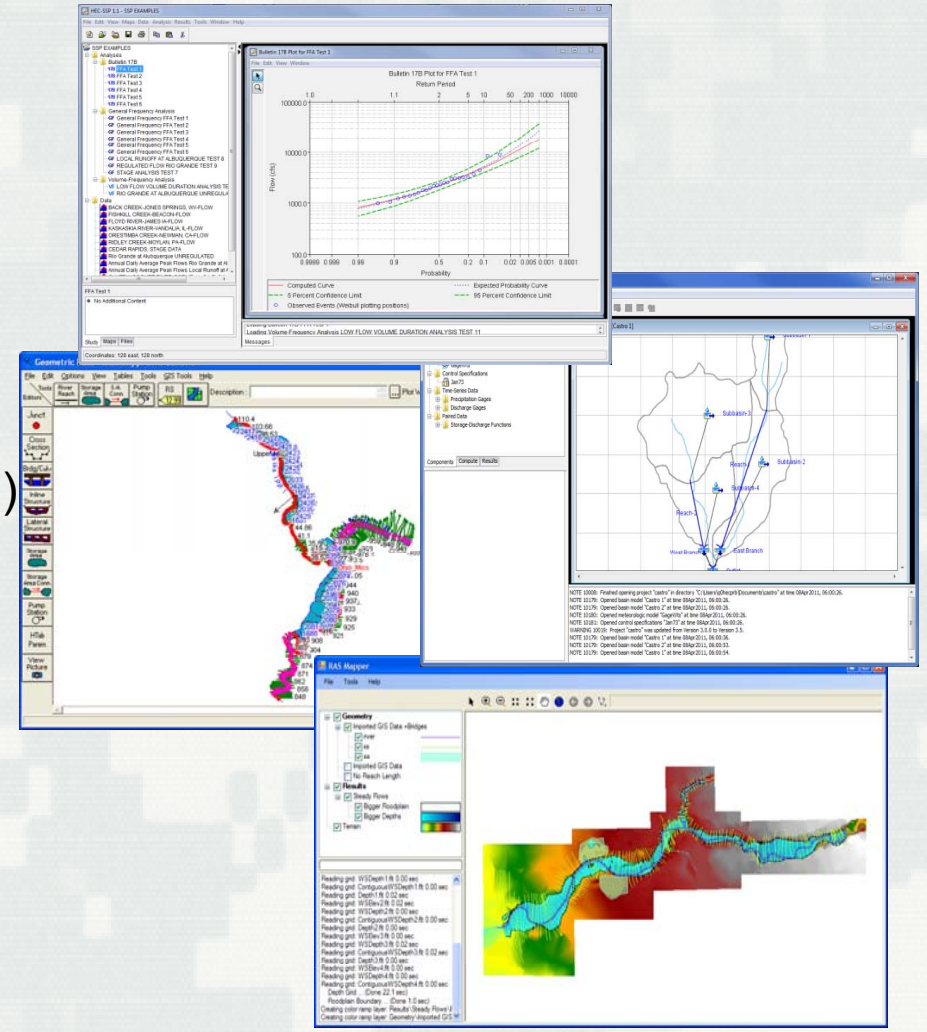
- Solve problems in a general manner for use everywhere.
- Complete product line for hydrologic and hydraulic engineering software:
  - Hydrologic Statistics (SSP)
  - Watershed Hydrology (HMS & GeoHMS)
  - Reservoir Analysis (ResSim & PRM)
  - River Hydraulics (RAS & GeoRAS)
  - Flood Risk Management (FDA-FIA)
  - Ecosystem Functions (EFM & GeoEFM)

  Integrating Technologies
  - Data Storage System (DSSVue)
  - Real-Time Forecasting (CWMS)
  - Watershed Analysis (WAT & FRA)



Outline

- HEC-HMS Sediment and Water Quality – *Bill & Jay*
- HEC-ResSim Water Quality – *Todd*
- HEC-RAS Water Quality – *Mark*
- HEC-RAS Sediment – *Stanford*
- HEC-EFM – *John*

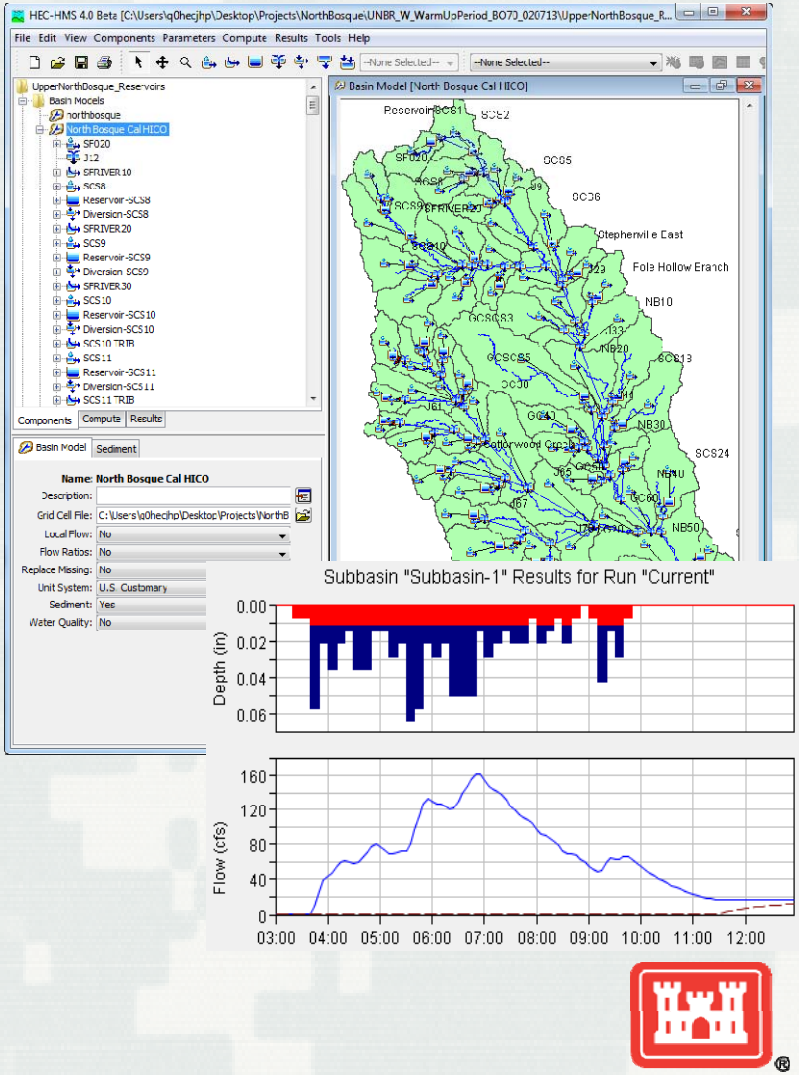
HEC-HMS
Sediment and Water Quality

Bill Scharffenberg & Jay Pak

HEC-HMS

Hydrologic Modeling System

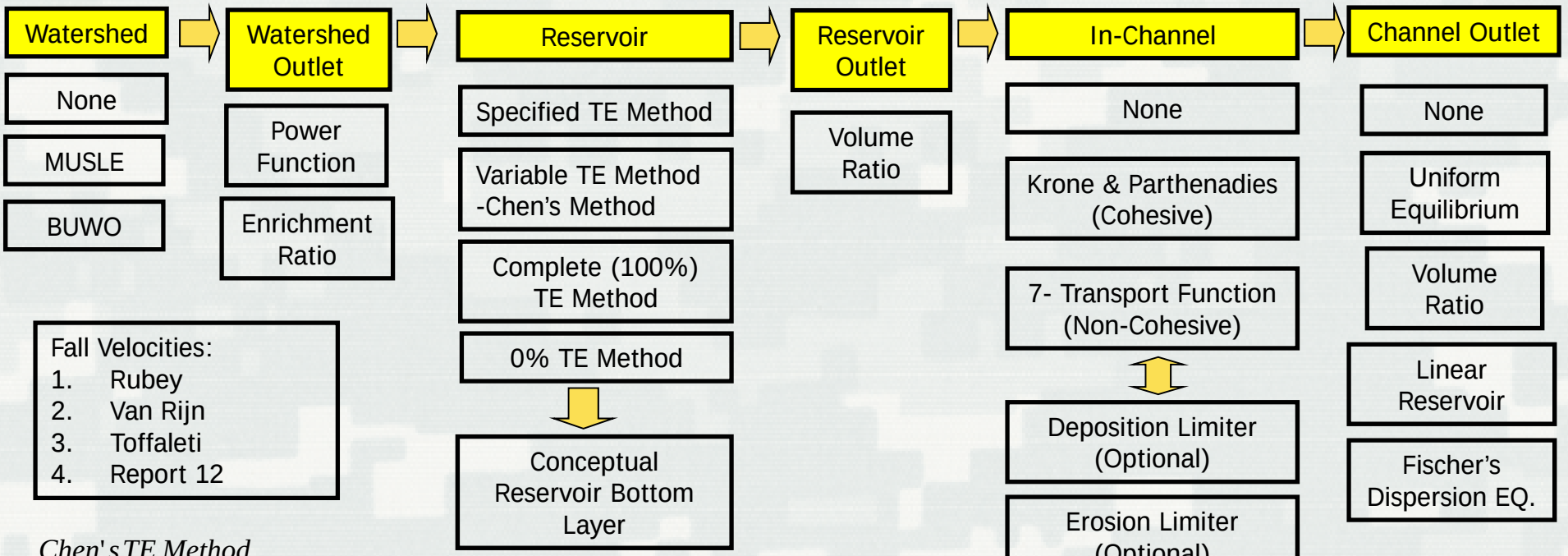
- A fully-featured hydrologic modeling system to support a wide range of water resource study goals.
- Integrated work environment with tools for data entry, mapping, simulation, parameter estimation, and results visualization.
- The full scope of the hydrologic cycle is encompassed:
  - Precipitation.
  - Potential evapo-transpiration.
  - Snowmelt.
  - Canopy interception.
  - Surface depression storage
  - Infiltration.
  - Surface runoff
  - Baseflow
  - Channel routing, with optional losses.



HEC-HMS Version
Sediment Transport Module (STM)

- Erosion is a concern in a watershed.
- Sediment is also a concern.
- Many planning studies now consider environmental management along with flood damage reduction.
- HEC-HMS 4.0 is planned to include surface erosion and sediment transport.
  - Simulate sediment yield from the land surface and transport sediment through the reservoirs and channels.
  - Provide boundary conditions for the hydraulics models
  - Can be used for TMDL study for sediments

HEC-HMS
Sediment Transport Processes



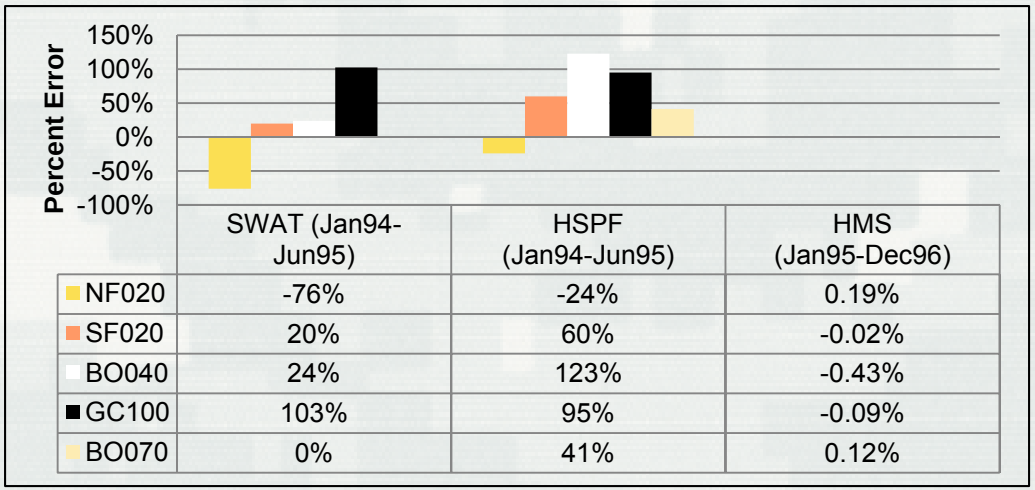
Chen's TE Method

$$TE = 100\left[1 - e^{-\frac{v_s}{v_c}}\right] \quad for\ turbulent\ flow$$

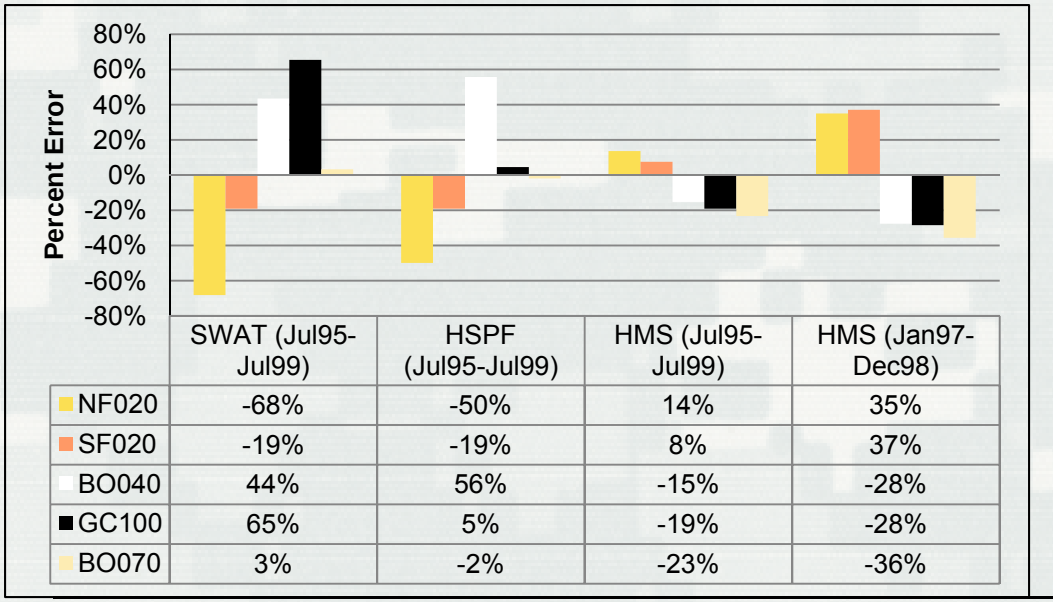
Volume Ratio

$$Sed_{out} = \frac{Volume_{out}}{Volume_{channel}} Sed_{channel}$$

Case Study Results: Upper North Bosque River watershed

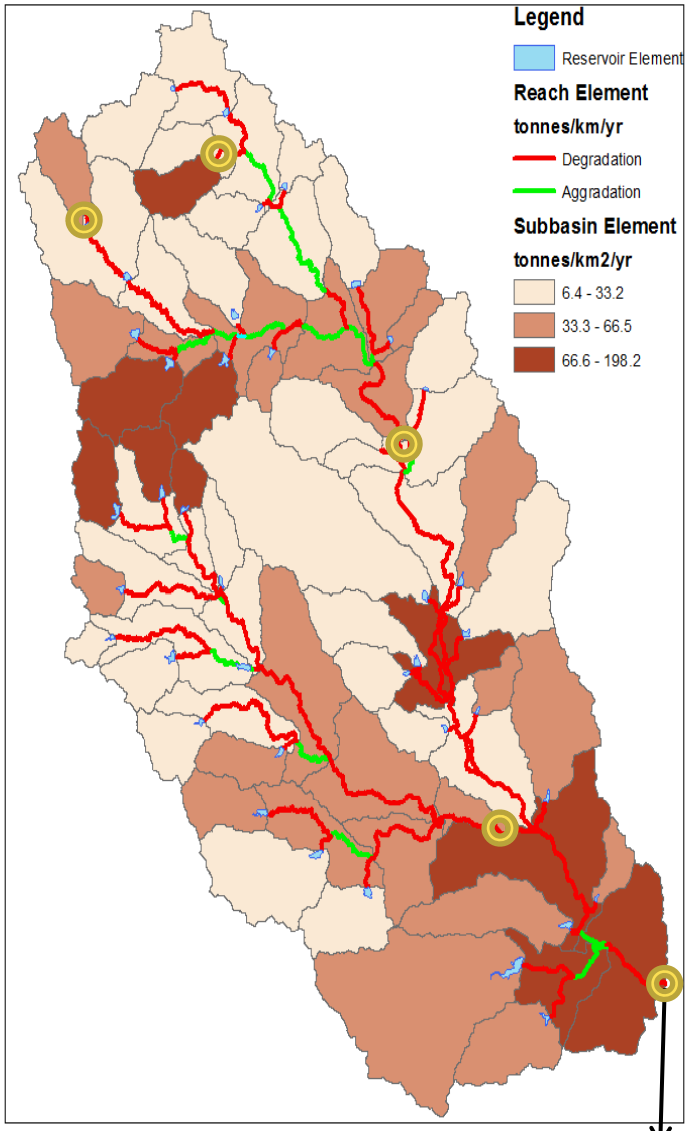


	SWAT (Jan94-Jun95)	HSPF (Jan94-Jun95)	HMS (Jan95-Dec96)
NF020	-76%	-24%	0.19%
SF020	20%	60%	-0.02%
BO040	24%	123%	-0.43%
GC100	103%	95%	-0.09%
BO070	0%	41%	0.12%



	SWAT (Jul95-Jul99)	HSPF (Jul95-Jul99)	HMS (Jul95-Jul99)	HMS (Jan97-Dec98)
NF020	-68%	-50%	14%	35%
SF020	-19%	-19%	8%	37%
BO040	44%	56%	-15%	-28%
GC100	65%	5%	-19%	-28%
BO070	3%	-2%	-23%	-36%

Source for SWAT and HSPF results: Saleh, A, and Du, B. (2004)

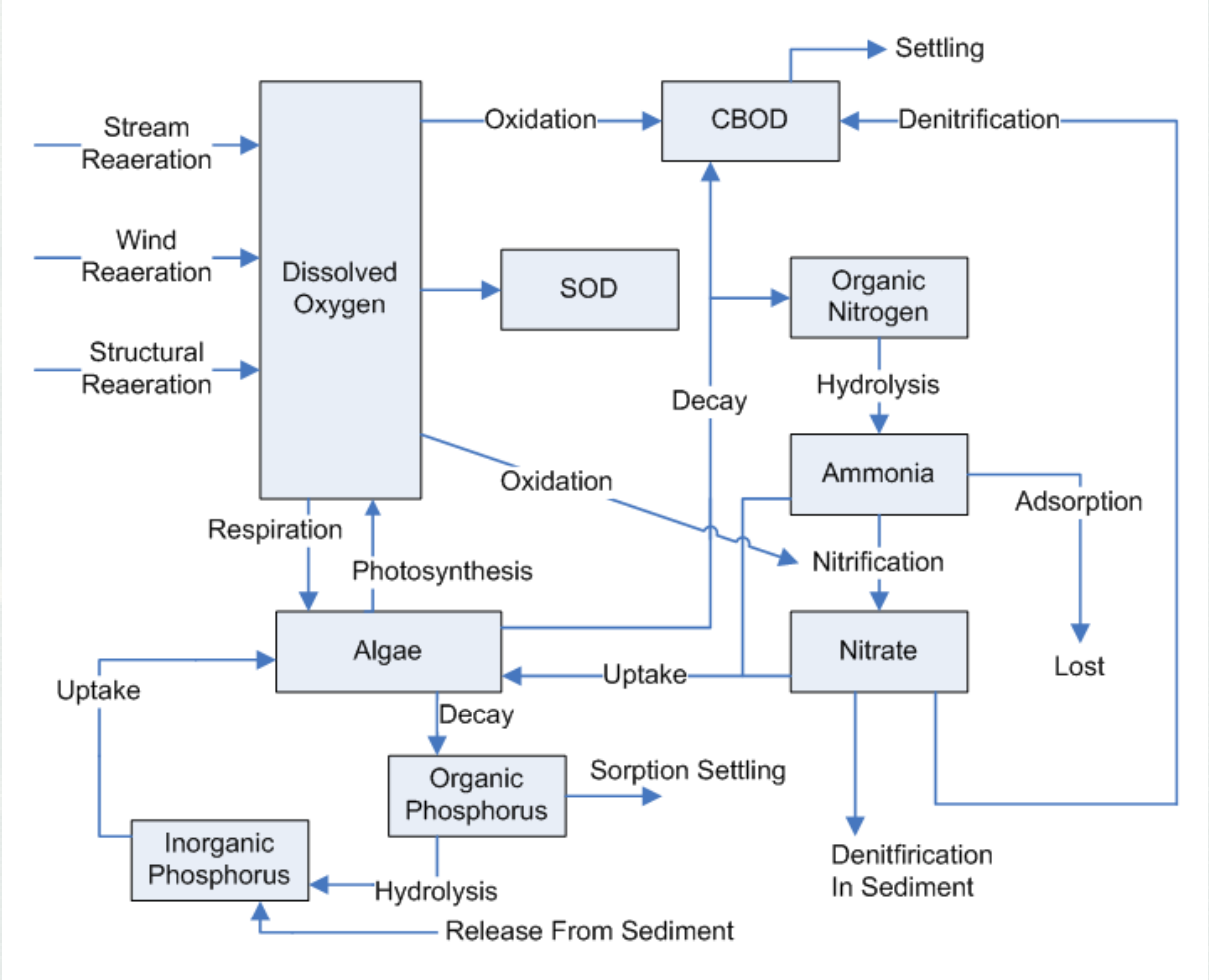


Sediment Boundary Condition

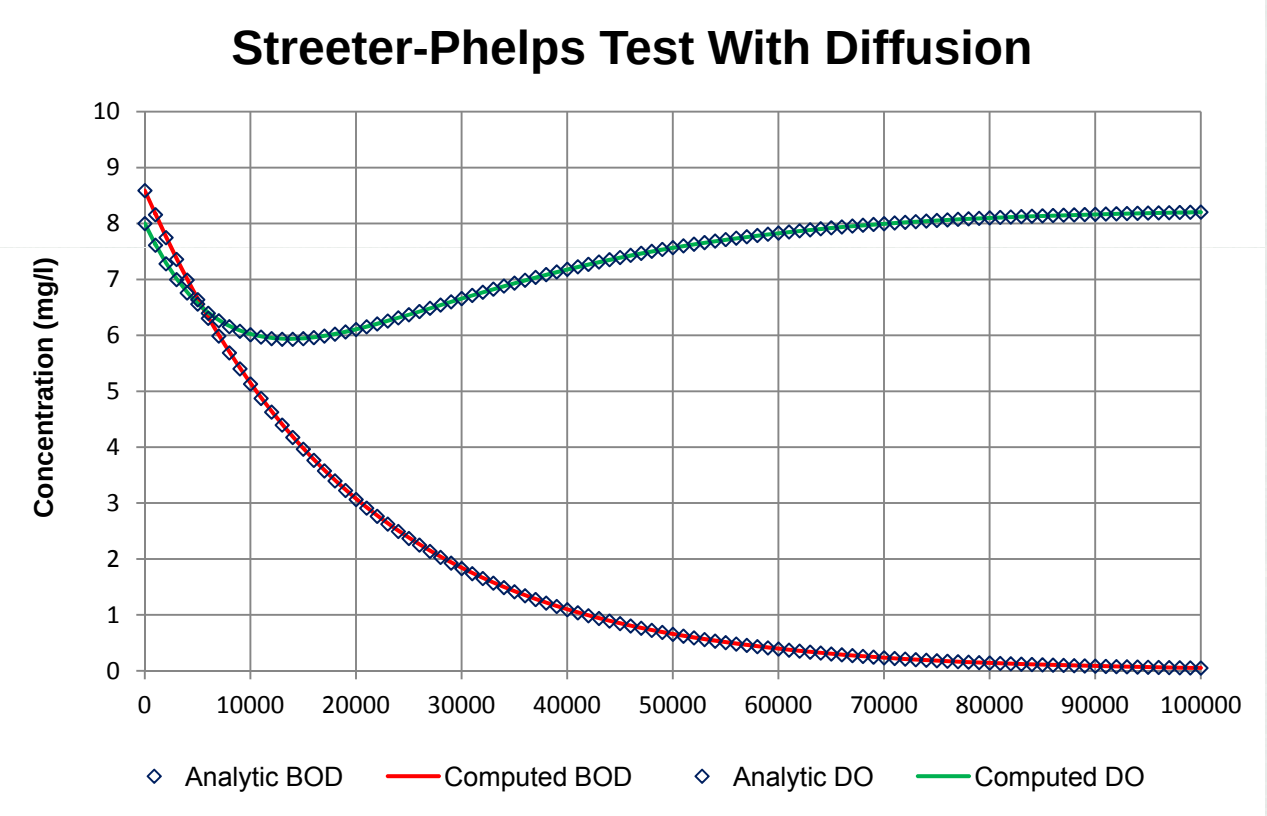
HEC-HMS
Nutrient Simulation Module (NSM)

- Nutrient Simulation Module (NSM) simulates nitrogen and phosphorus species in the aquatic environment (ERDC/EL TR-08-25).
- Implemented for reach and reservoir elements.
- Future work will add canopy consumption from soil, decay and wash-off of surface organics, and transformations in the soil.
  - Provide boundary conditions for the hydraulics models.
  - Can be used for TMDL study for nutrients.

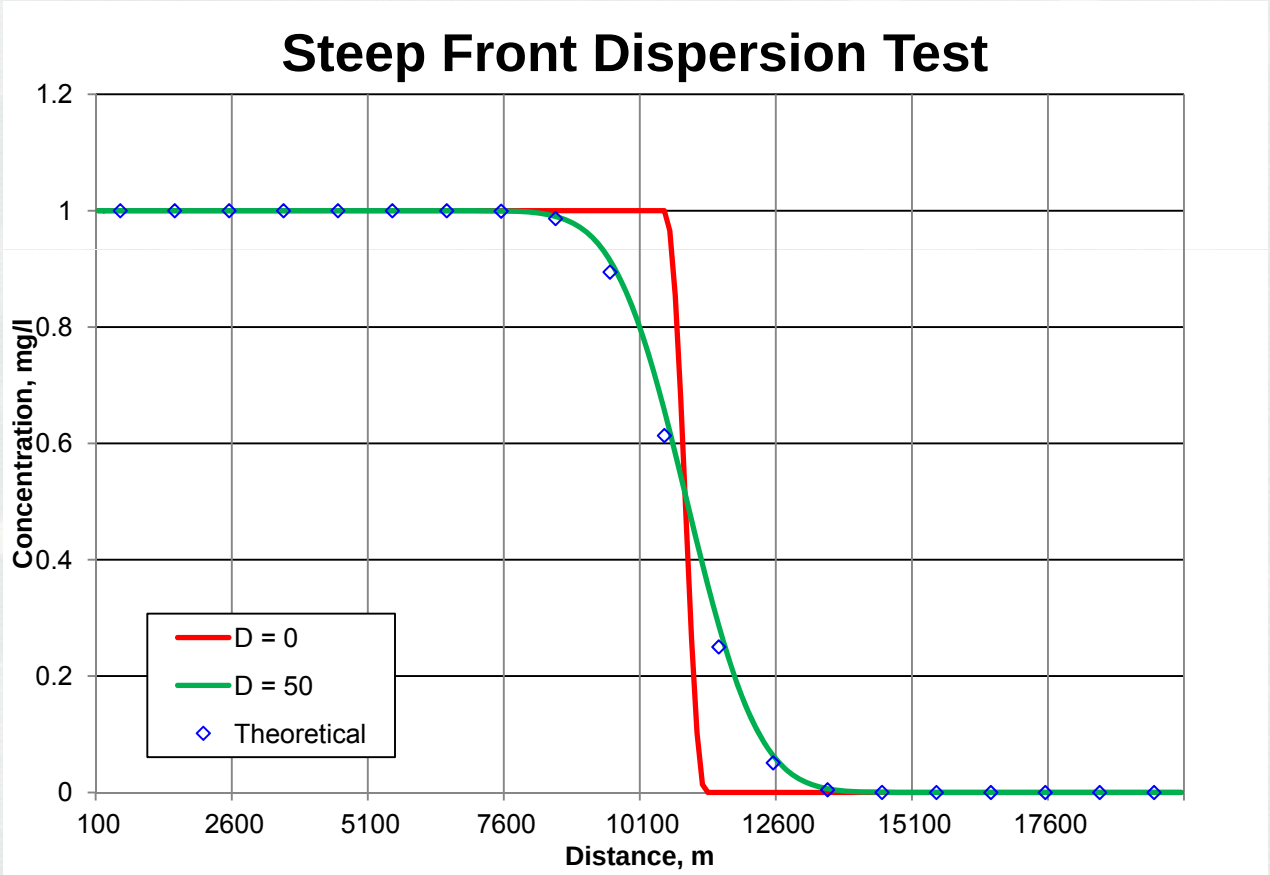
HEC-HMS
Nutrient Simulation Module (NSM)



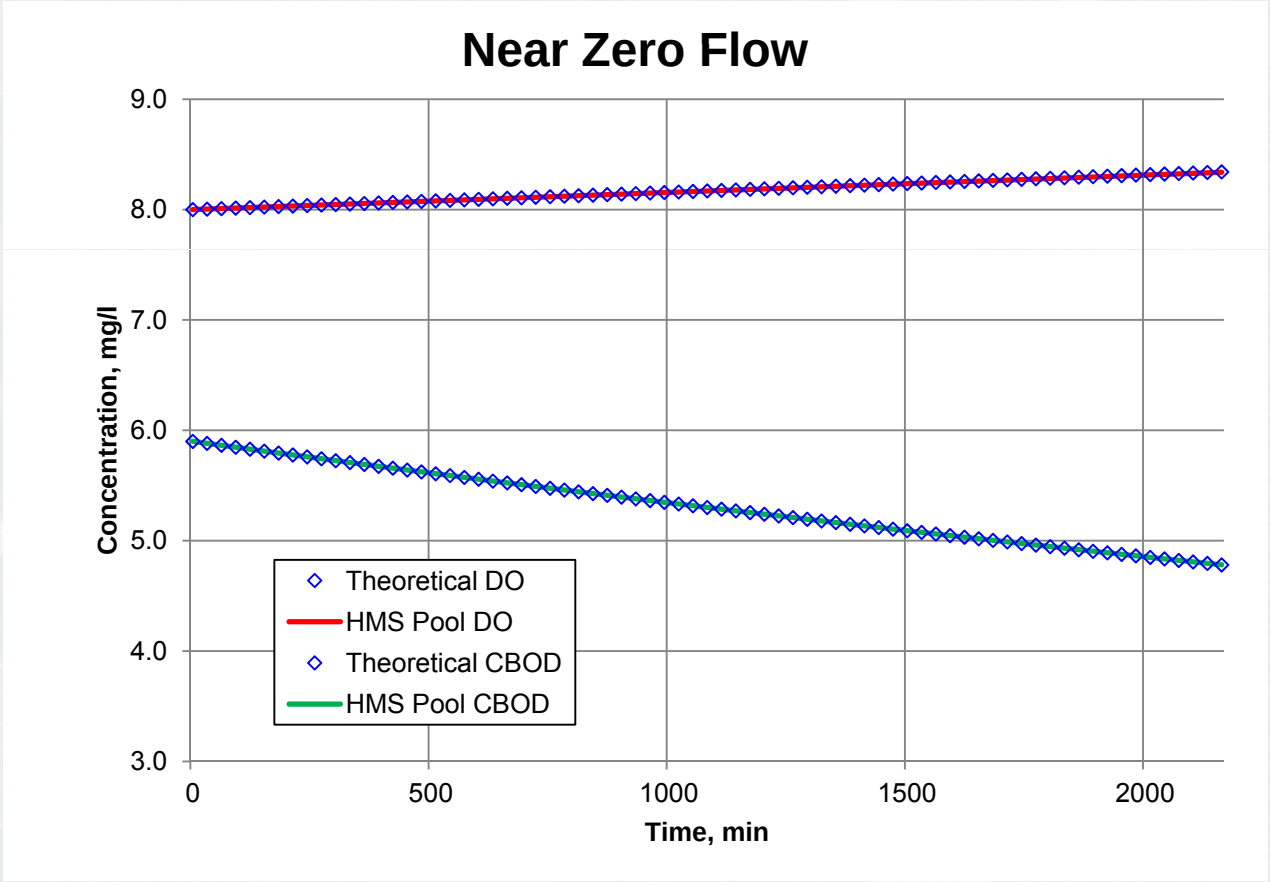
HEC-HMS
Nutrient Simulation Module (NSM)



HEC-HMS
Nutrient Simulation Module (NSM)



HEC-HMS
Nutrient Simulation Module (NSM)



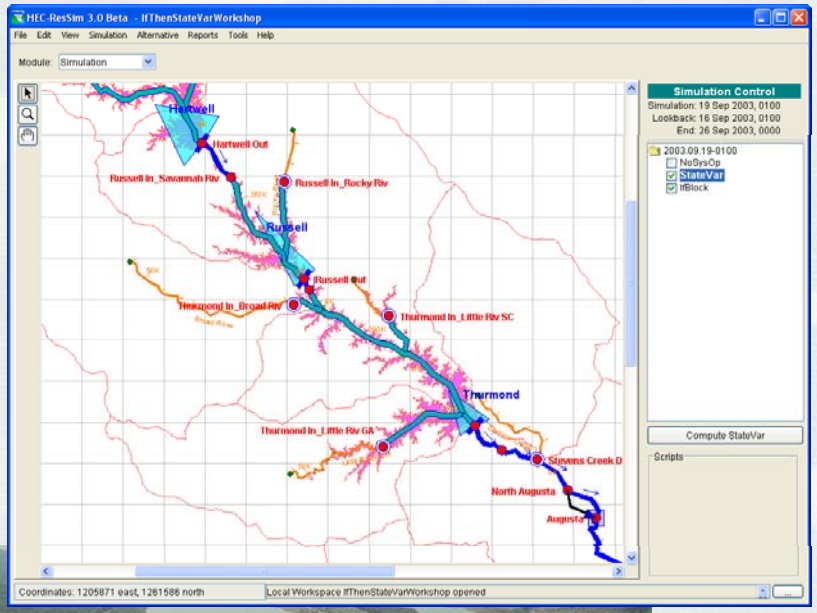
HEC-ResSim Water Quality

Todd Steissberg

HEC-ResSim

Reservoir System Analysis

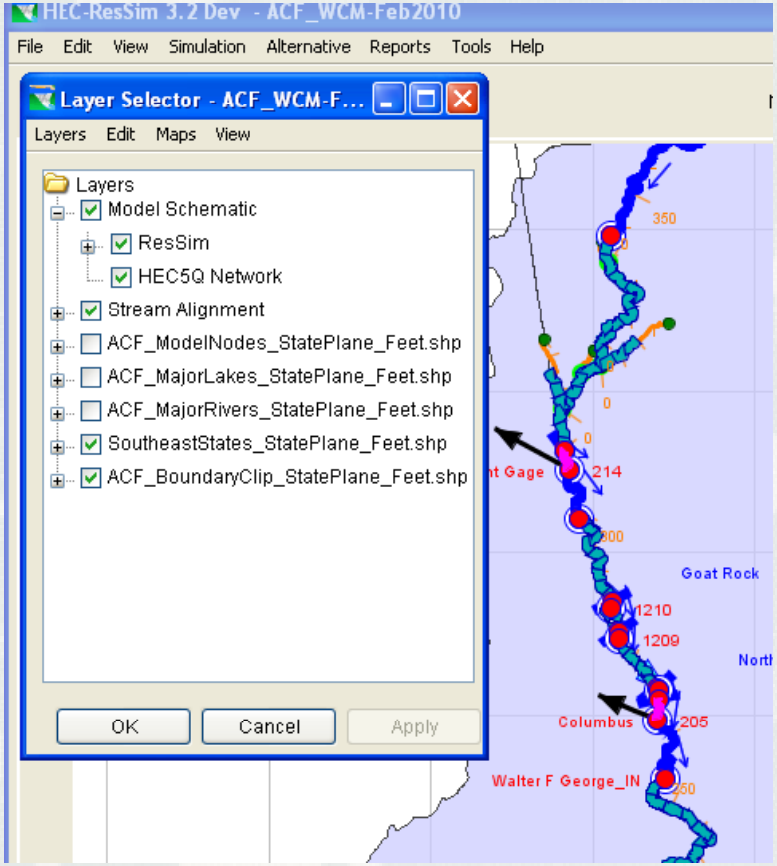
- Simulates reservoir operations
  - Balance and manage conflicting demands (environment, flood protection, water & power supply, navigation, recreation, etc.) using a simple or complex set of rules
  - Planning studies
  - Real-time decision support
- Environmental Flows
  - Dilution vs. pollution
  - Habitat (flow quantity, timing, pulses)
- Water Quality and Ecology (via CE-QUAL-W2 and HEC-5Q)
  - Water temperature
  - Dissolved oxygen
  - Nutrients
  - In-pool habitat assessment
  - Selective withdrawal



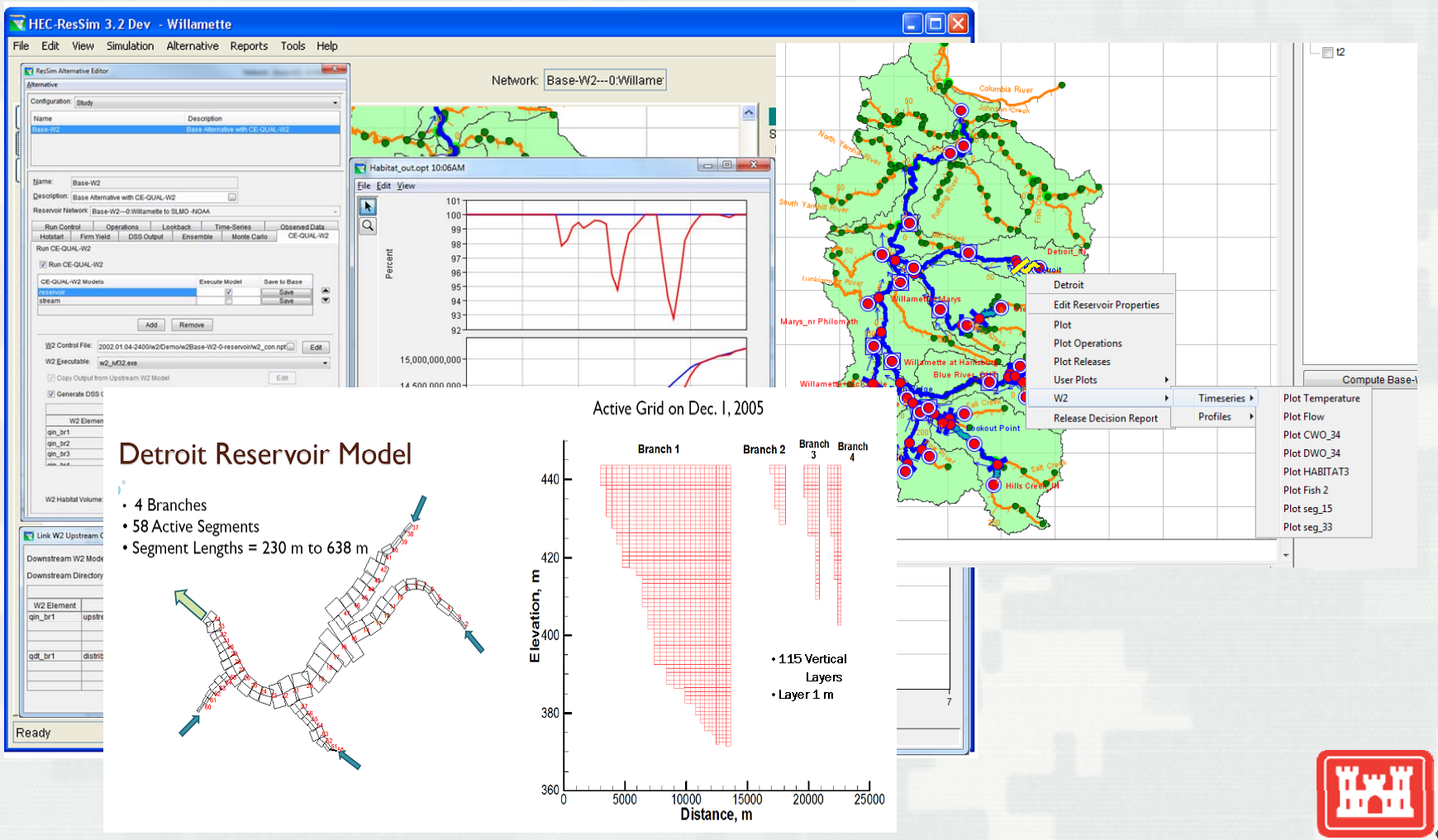
HEC-ResSim

Reservoir Operations for Water Quality

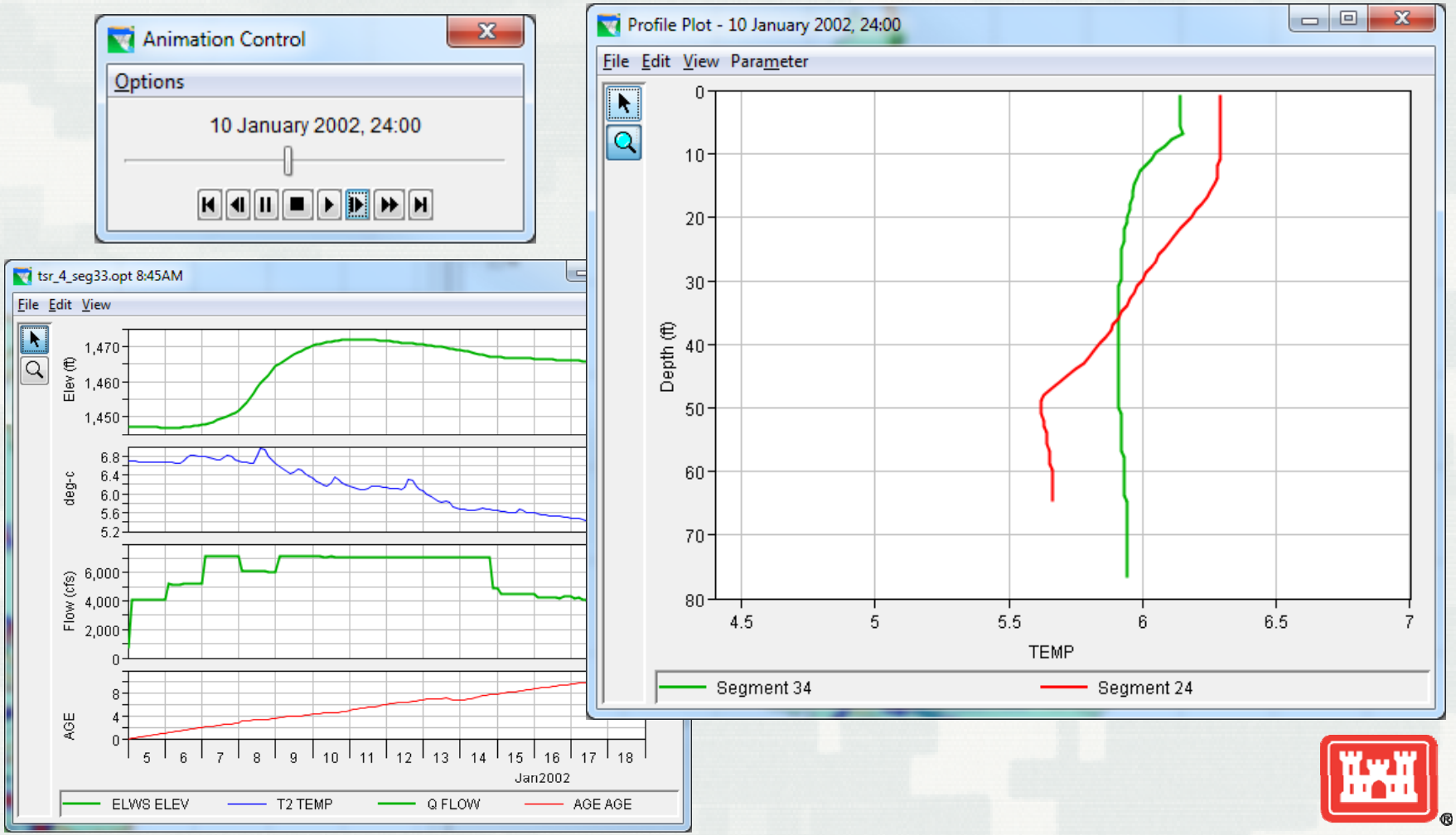
- CE-QUAL-W2 and HEC-5Q “plug-ins” add water quality simulation capability to HEC-ResSim
- The coupled models combine the water quality simulation strengths of HEC-5Q and CE-QUAL-W2 with the operational management, visualization, and analysis capabilities of HEC-ResSim
  - Analyze multiple scenarios and simulation periods
  - Link multiple individual water quality models into a single watershed-scale model, coupled with HEC-ResSim flows
  - Visualize water quality results using HEC-ResSim interface



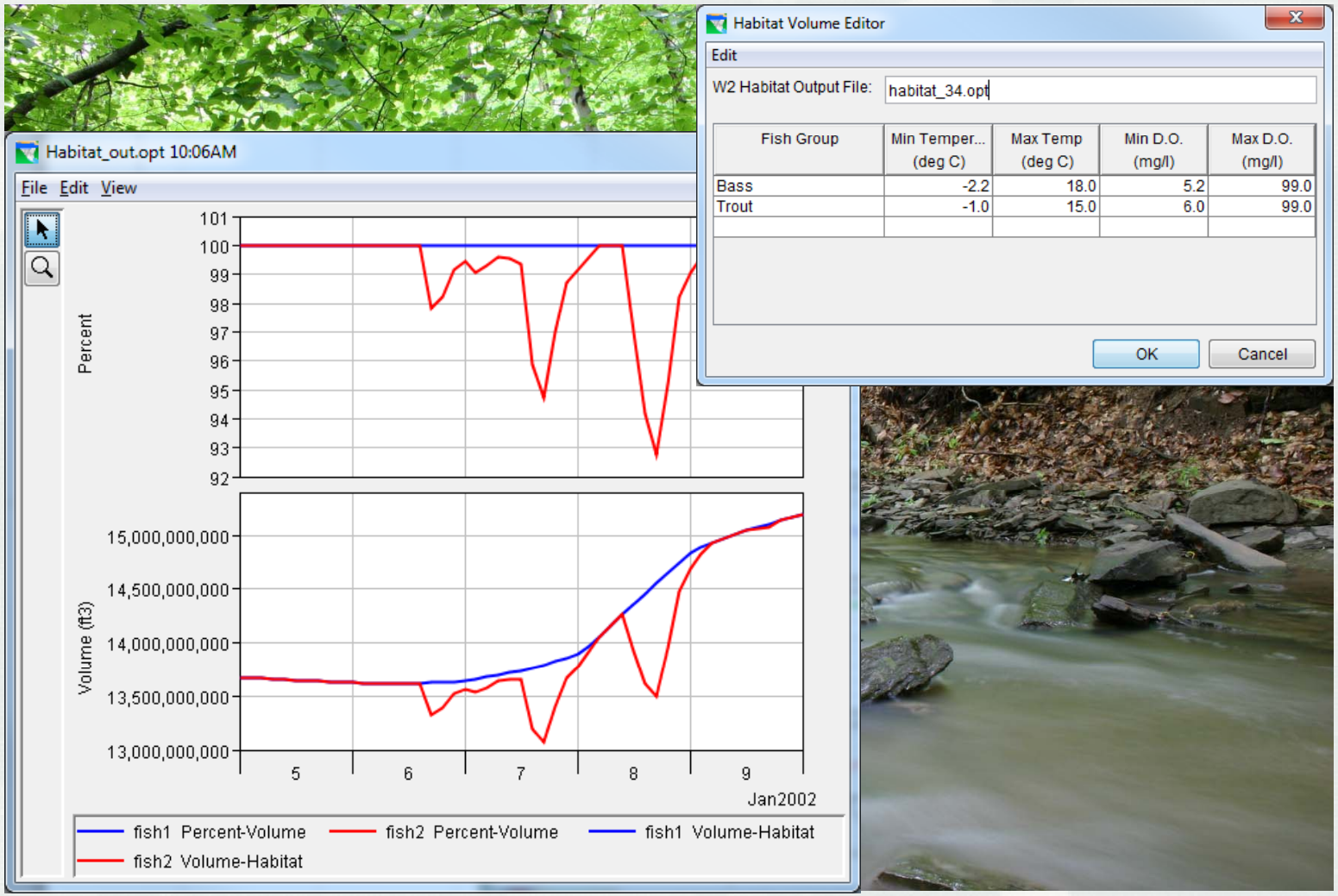
Coupled Operational and Water Quality Models: Reservoir and Stream Water Quality



Time Series and Animated Vertical Profiles



Habitat Volume (CE-QUAL-W2)



Features Summary and Applications

- Environmental flows - for water quality and habitat
- System-wide analysis and management of water quality
- Test multiple operational scenarios to improve downstream water quality and fish habitat
- Integration of new CE-QUAL-W2 features:
  - Habitat Volume: compute the volume of viable in-pool habitat for any number of fish species, by temperature and D.O.
  - Selective Withdrawal: adjust operations to achieve a target outflow temperature at dams with selective withdrawal capability
    - Increase releases from deeper outlets to decrease outflow temperatures to improve fish habitat for cool-water species
- Applications:
  - Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa Watersheds, AL & GA (HEC-5Q, 2009 – present)
  - Willamette (OR) and Lehigh (PA) Basin Demonstration Projects (W2, 2011)
  - System Temperature (SysTemp) modeling study of the Columbia River Basin (CE-QUAL-W2 and HEC-RAS via HEC-WAT, 2013 – 2015)

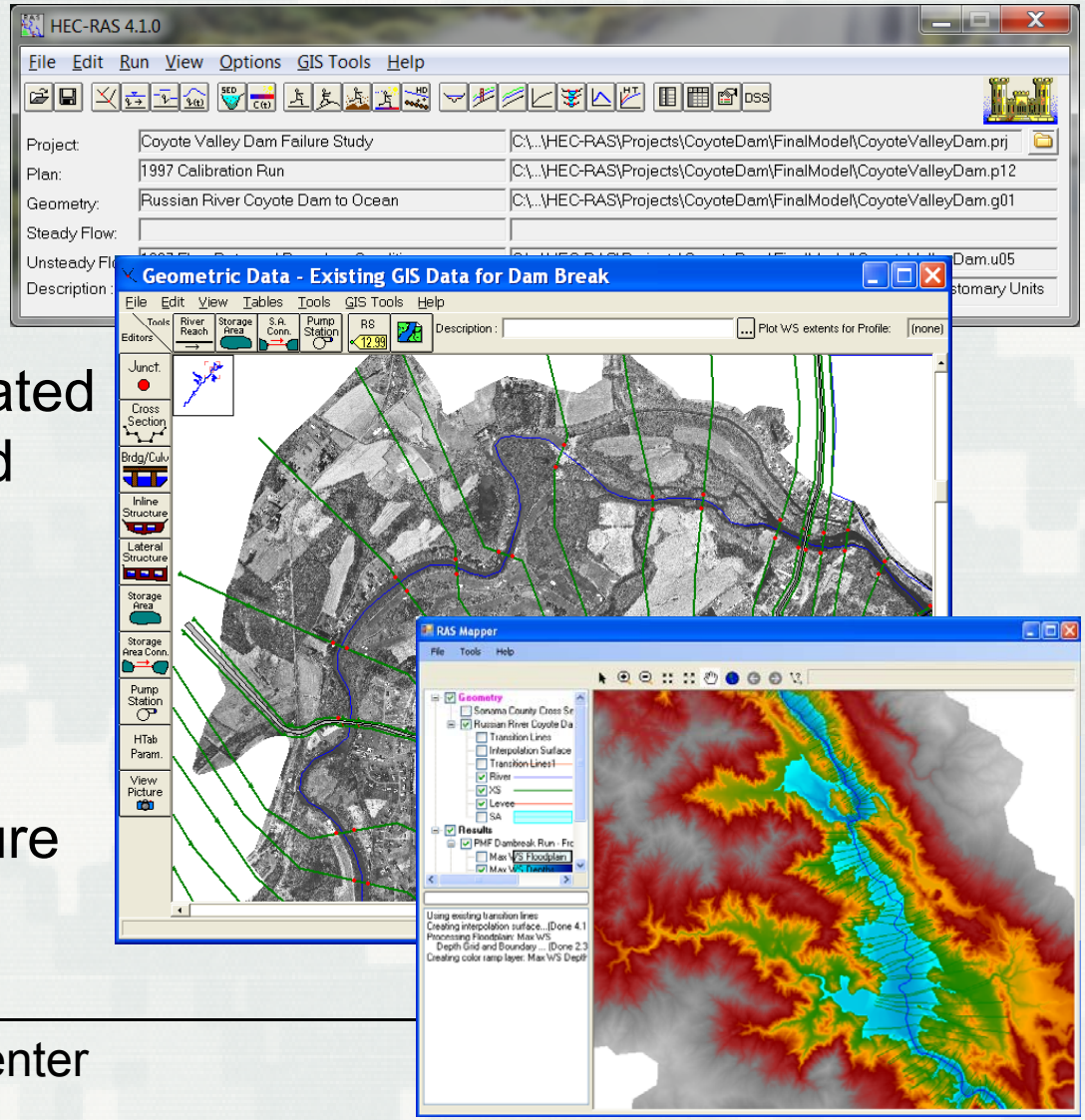
HEC-RAS

Mark Jensen & Stanford Gibson

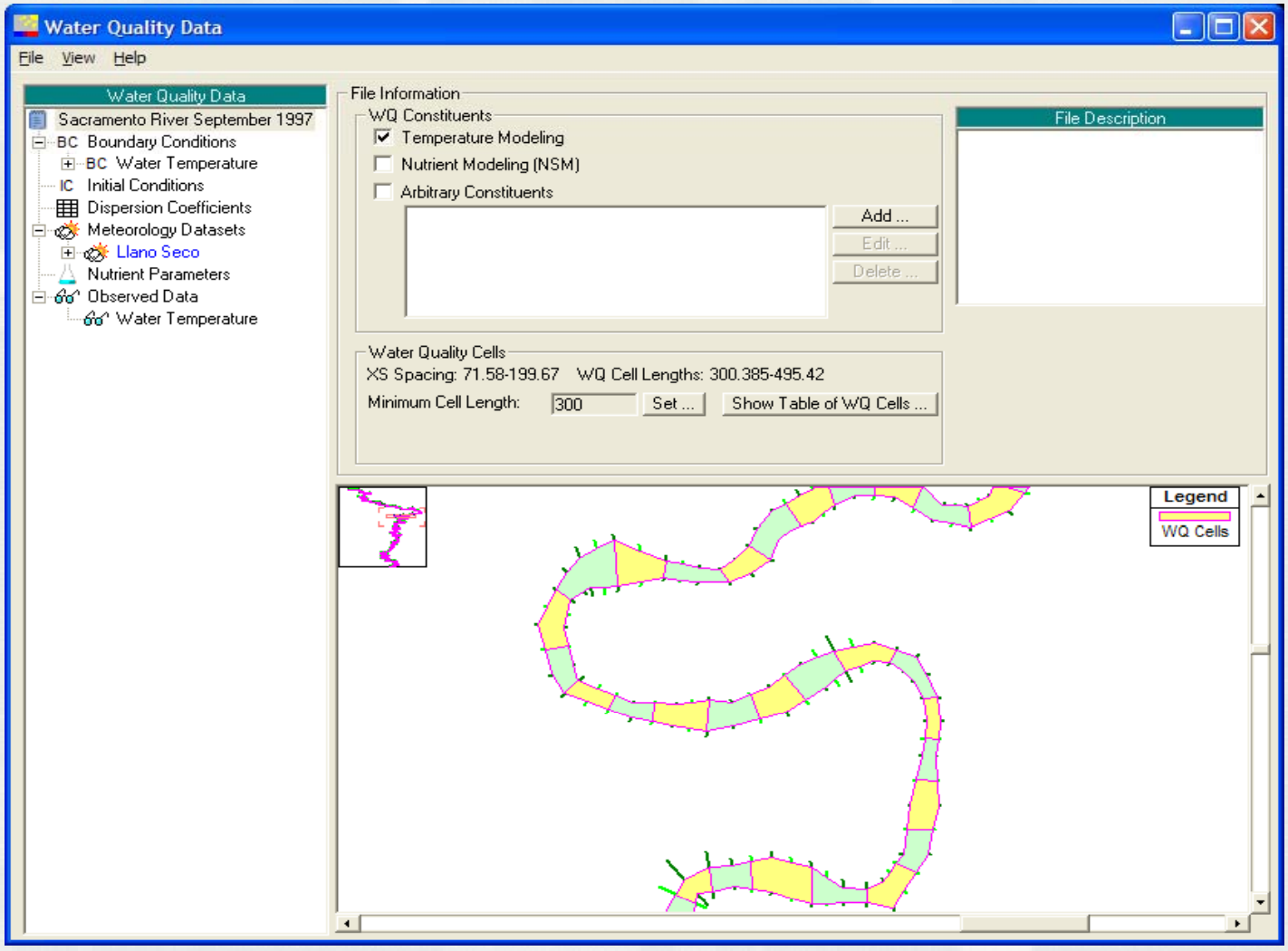
HEC-RAS

River Analysis System

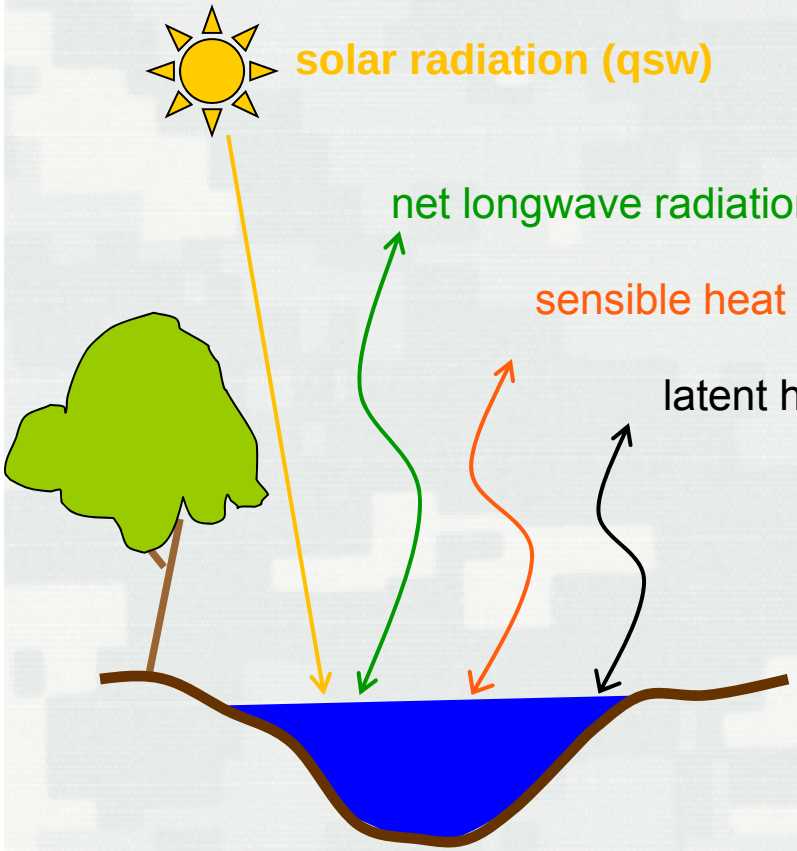
- One- and two-dimensional hydraulics program
- Computes river velocities, stages, profiles, and inundated areas given streamflow and geometry.
- Steady & Unsteady Flow
- Sediment Transport
- Water Quality & Temperature



Water Quality Modeling



Source/Sink Term for Temperature (Energy Budget)



solar radiation (qsw) — f (site location, time of day, day of year, atmospheric turbidity, cloud cover)

net longwave radiation (qlw) — f (air temperature, water temperature)

sensible heat (qh) — f (temperature gradient, wind, a&b)

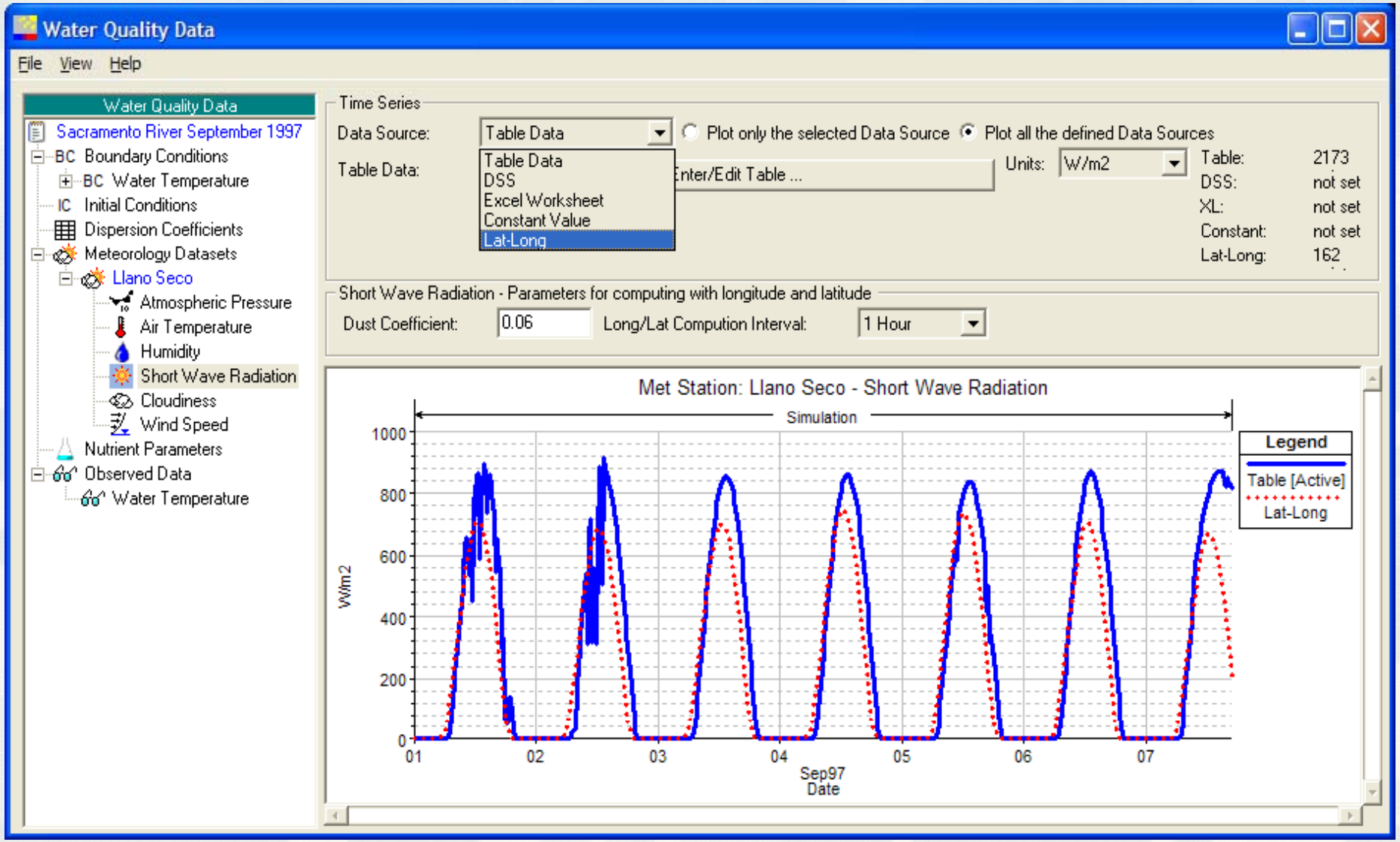
latent heat (qe) — f (vapor pressure gradient, wind, a&b)

$$q_{net} = q_{sw} + q_{lwn} + q_h + q_e$$

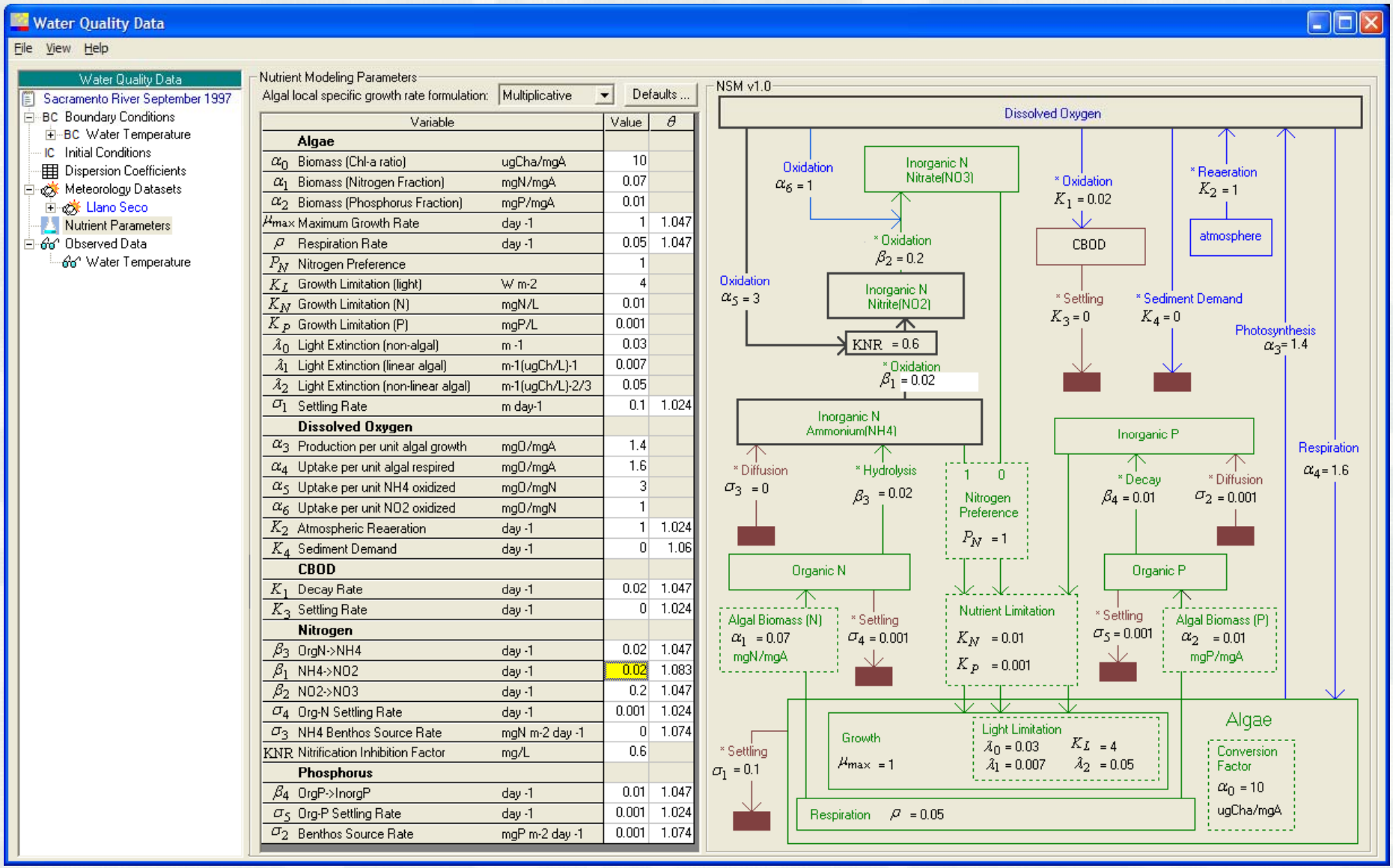
Planned:

- ground heat conduction
- shading (topographic, riparian)

Short Wave Radiation

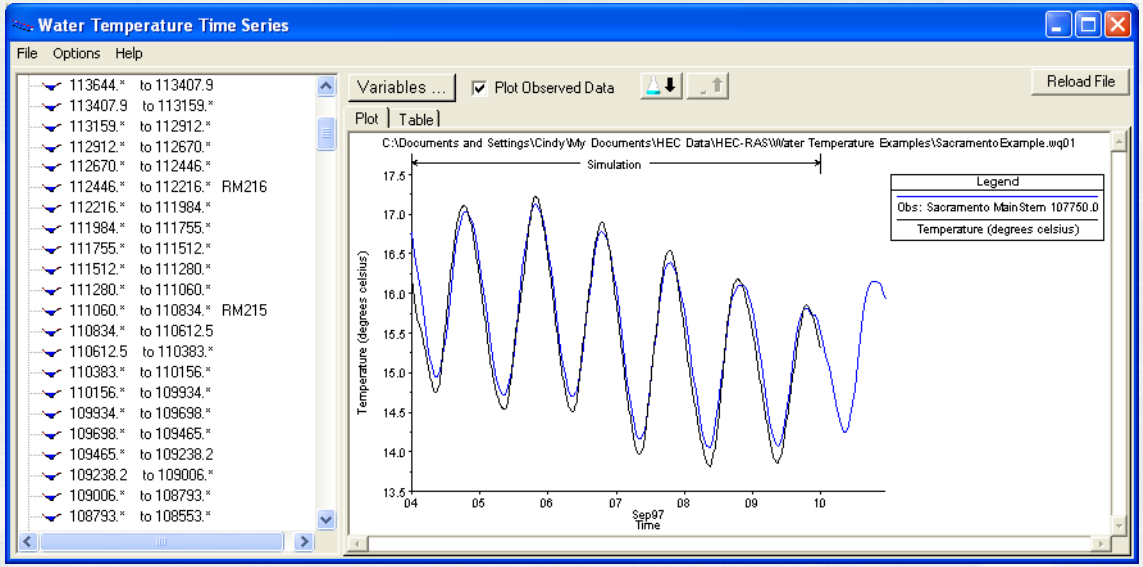


Nutrient Parameters

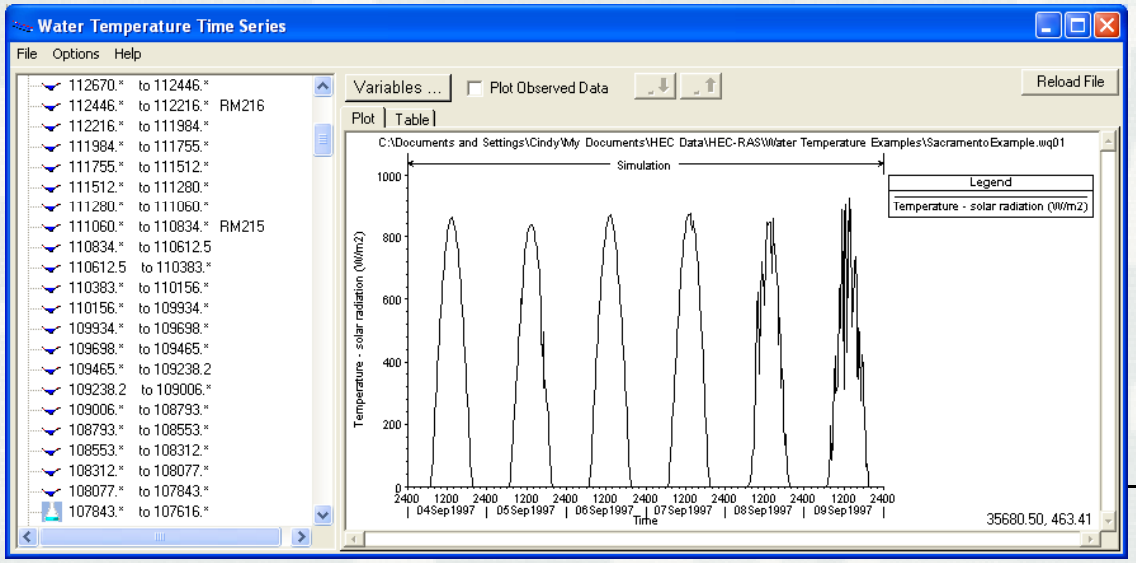


Sacramento River
Water Temperature

Time Series Plots



Water Temperature



Solar Radiation

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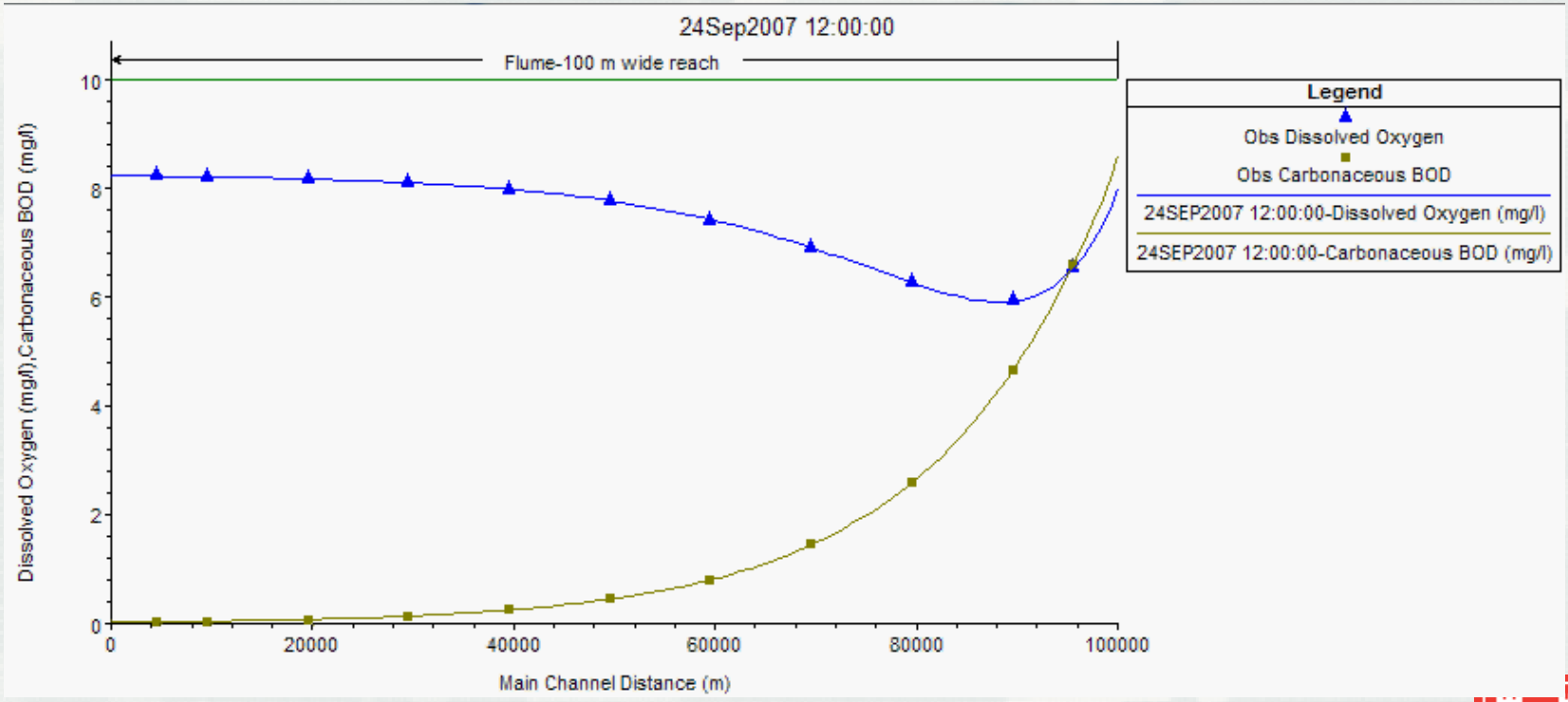
Streeter Phelps

$$DO = DO_{sat} - \frac{k\ BOD_0}{k_2 - k}\left(e^{-kx/u} - e^{-k_2 x/u}\right) - \left(DO_{sat} - DO_{initial}\right)\exp^{-k_2 x/u}$$

$$BOD = BOD_0 e^{-kx/u}$$



Applications

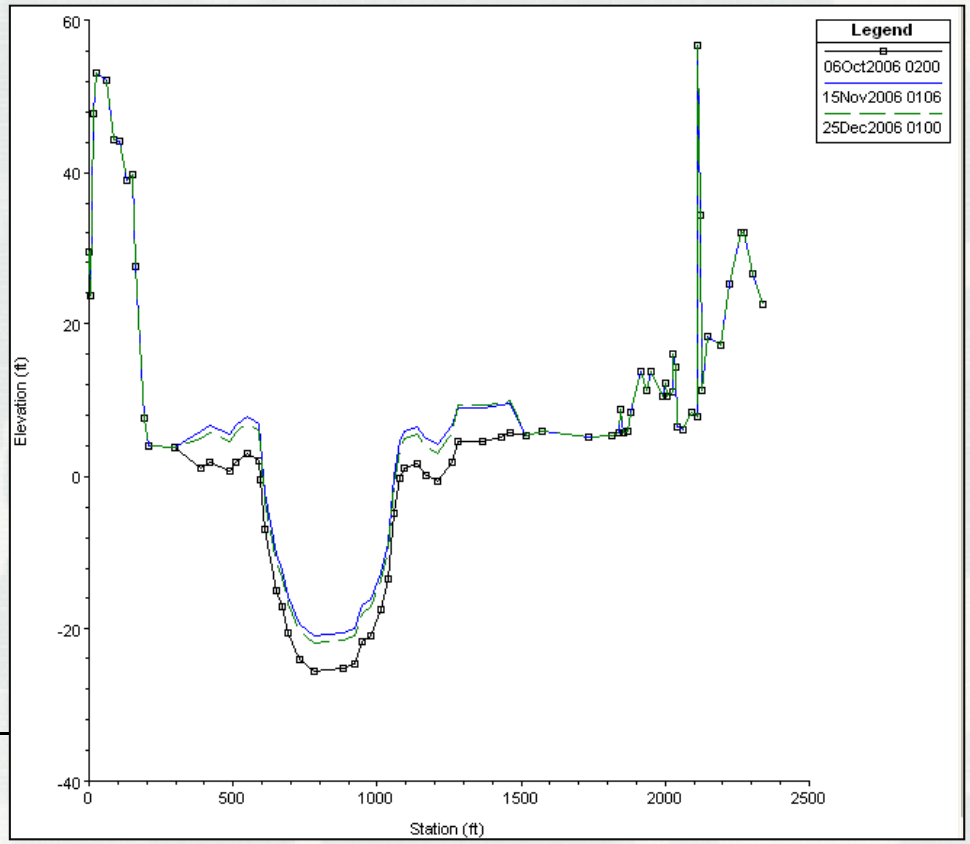
- Ohio River TMDL (EPA)
  - 1200 river miles of Ohio and Tributaries
  - > 10k combined sewer outfalls
- Columbia River Water Temperature Model
  - Calibrated for 3 years
  - 7 Alternatives explored

What's New For WQ?

- NSM II (Beta at end of this FY)
  - Based on Qual2K
  - 25 state variables
  - Carbon cycle
- Metals and Contaminants (2014?)
  - Needs carbon cycle for pH

Sediment Transport Modeling with HEC-RAS

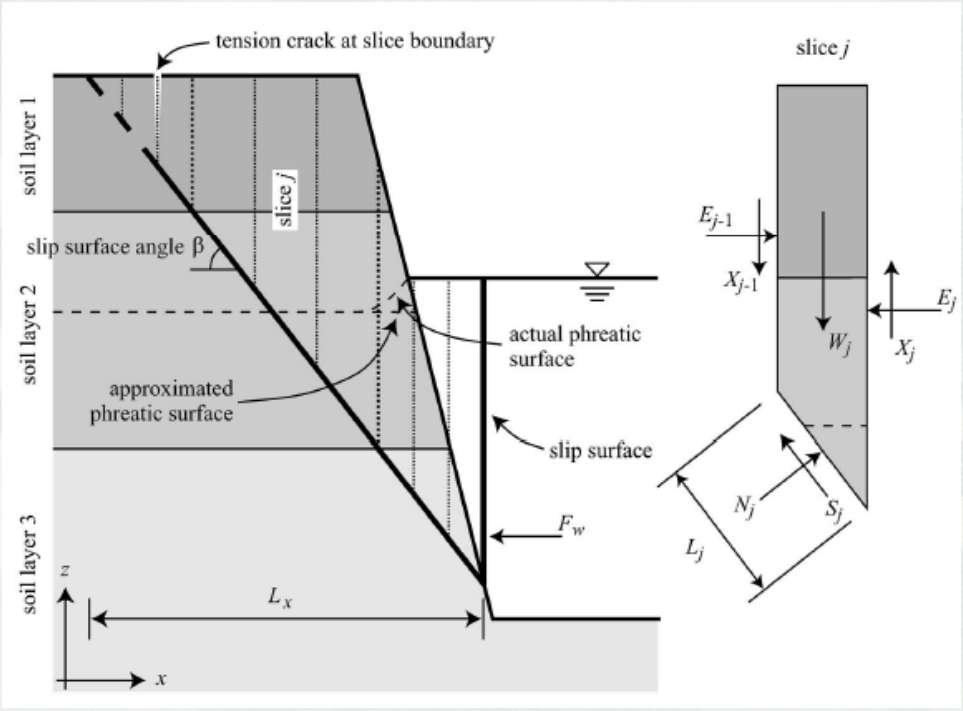
- Mobile Boundary Sediment Transport Modeling
  - Available since HEC-RAS version 4.0
  - Replicate Capabilities of HEC-6
- Routes sediment and updates cross sections and future hydraulics based on sediment transport.



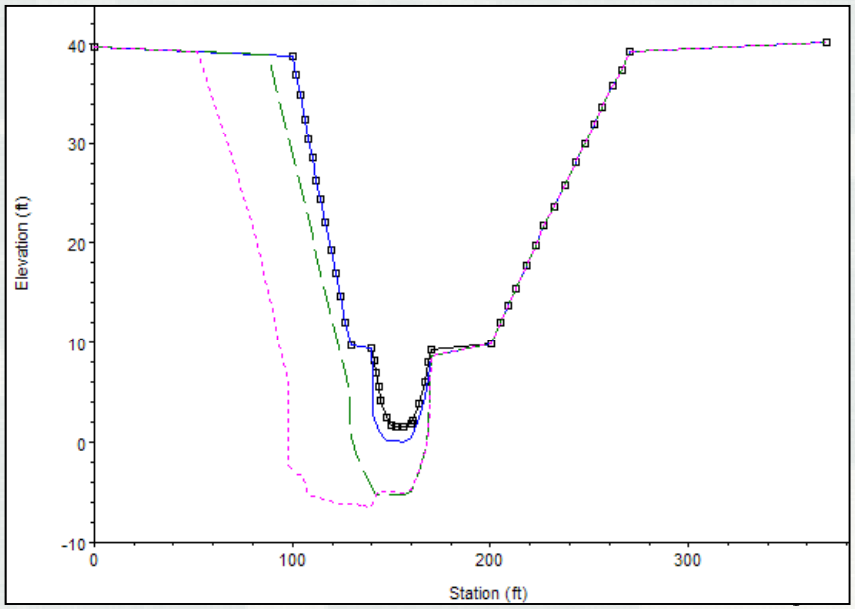
Sediment in HEC-RAS: Lateral Channel Migration- Toe Scour and Bank Failure

-Coupled HEC-RAS sediment transport mobile bed model with USDA-ARS Bank Stability and Toe Erosion Model (BSTEM)

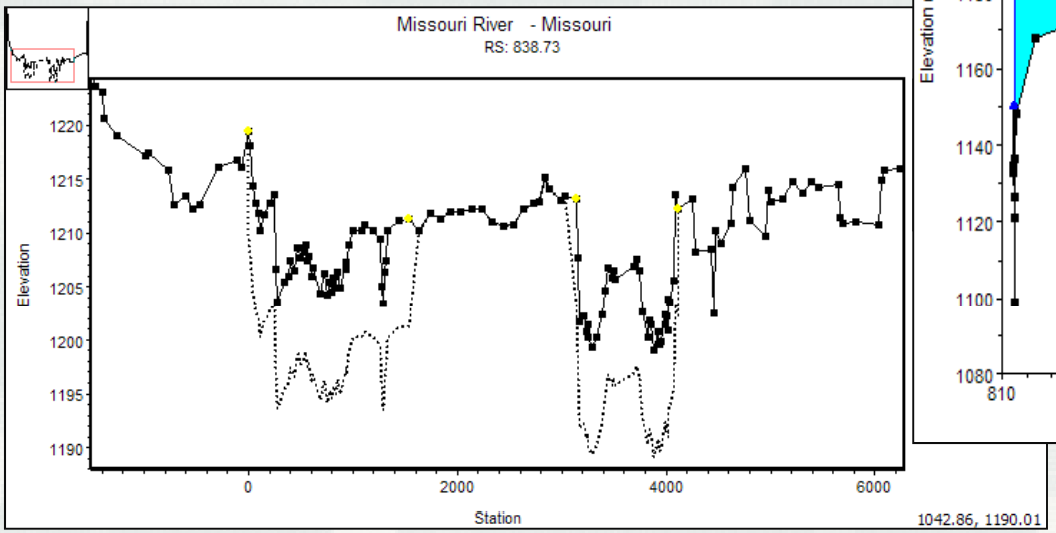
-Computes lateral scour and geotechnical\ bank failure

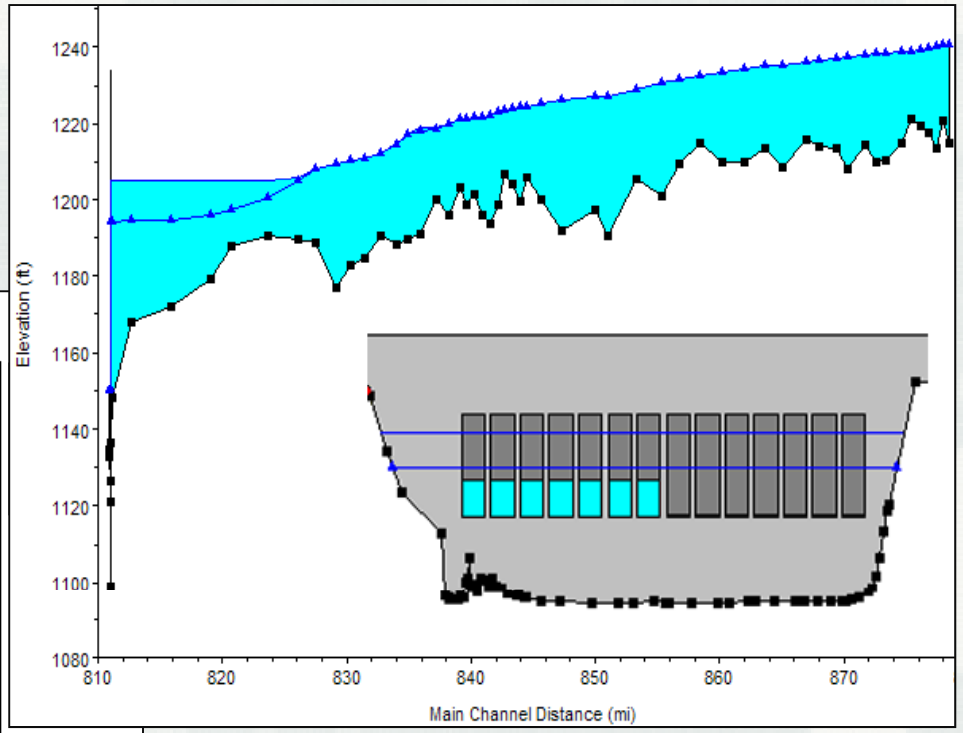



Blue River (NWK)



Sediment in HEC-RAS: Sustainable Reservoir Management Features





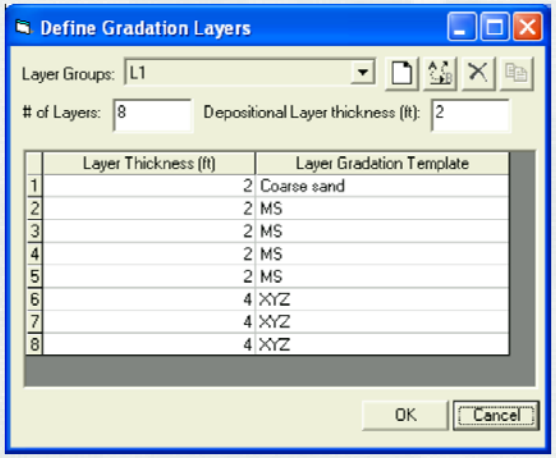

Niobrara and Missouri Confluence (NWO)

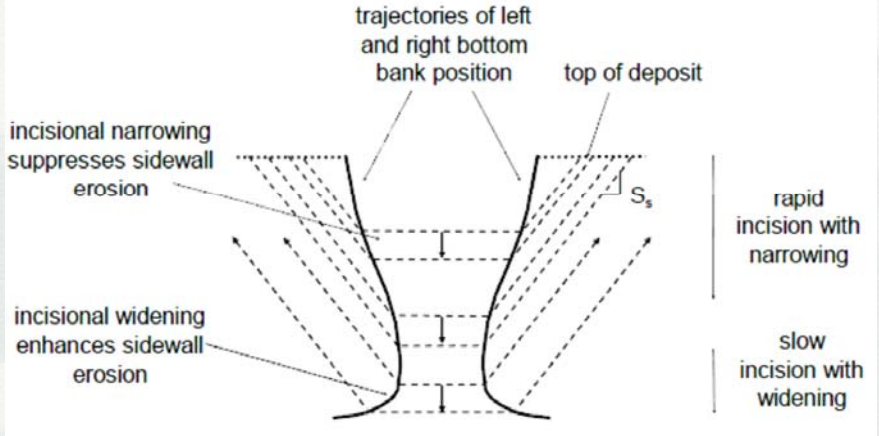
-Unsteady sediment transport

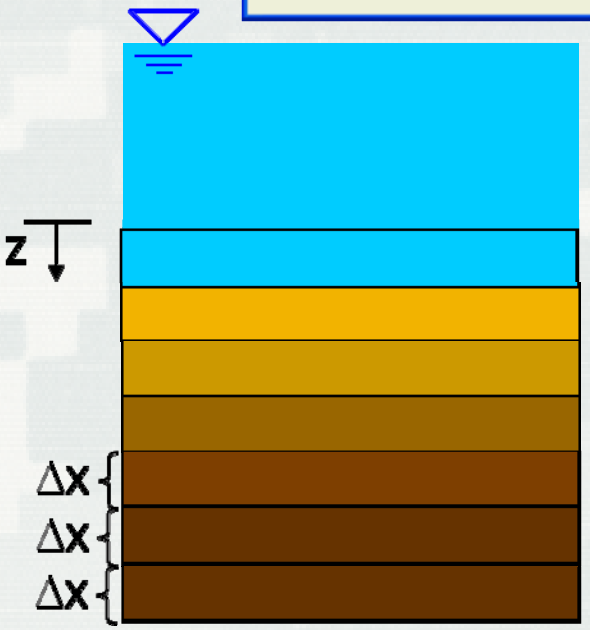
-Reservoir operation 'Rules' with sediment simulations → automatically operates reservoir based on user criteria

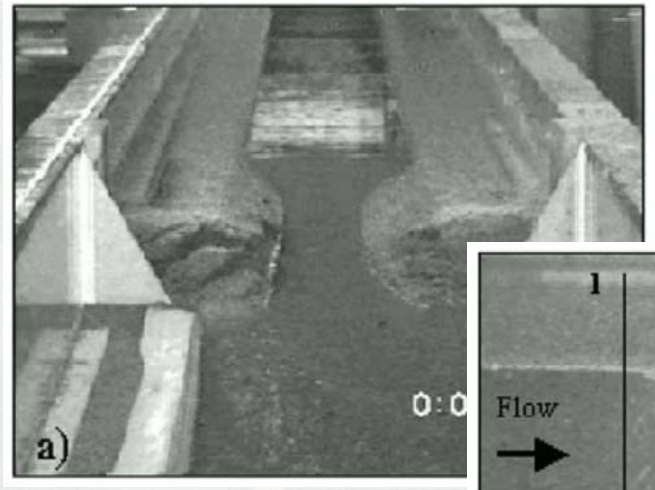
-Pilot flushing study on Gavin's Point Dam and the Lewis and Clark Reservoir

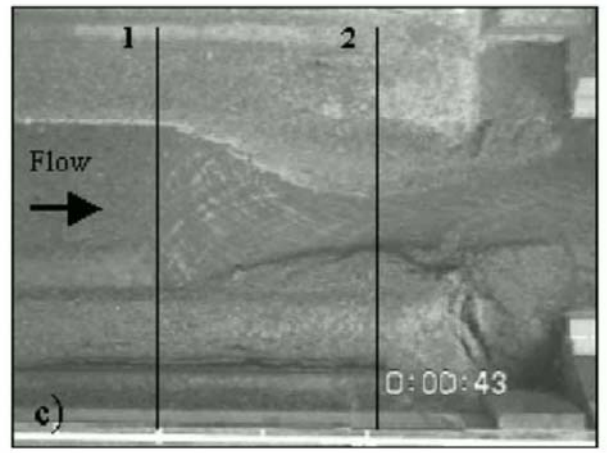
Sediment in HEC-RAS: Dam Removal Features





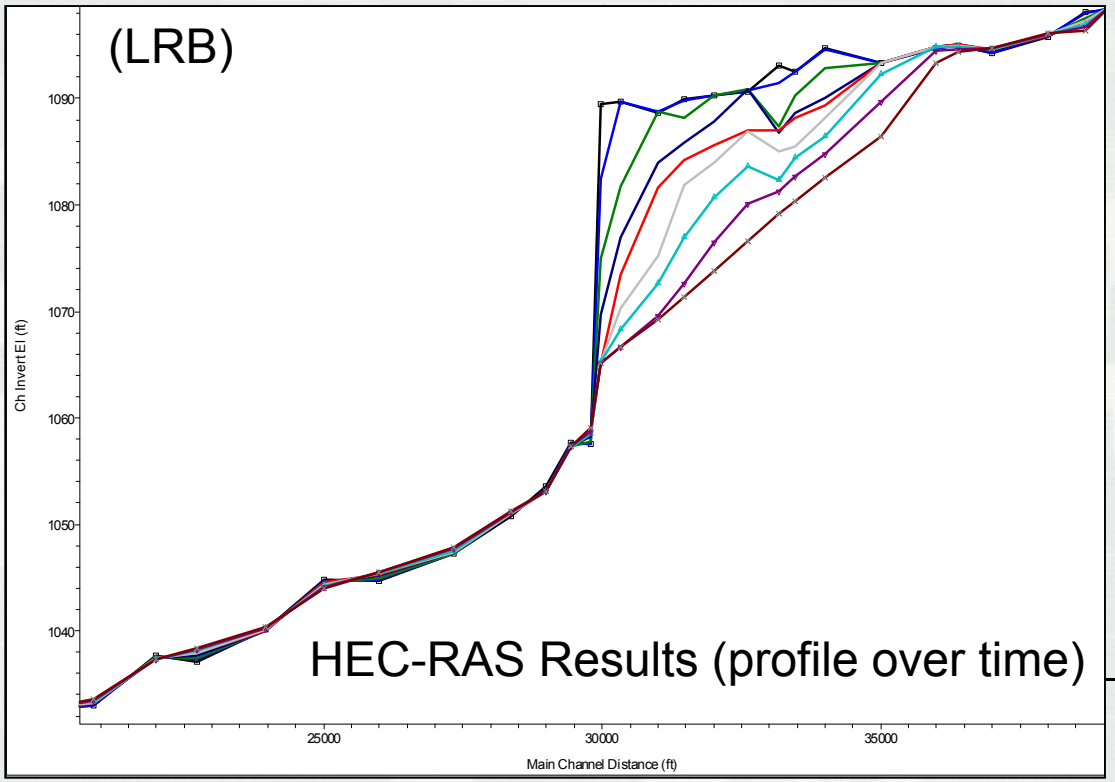


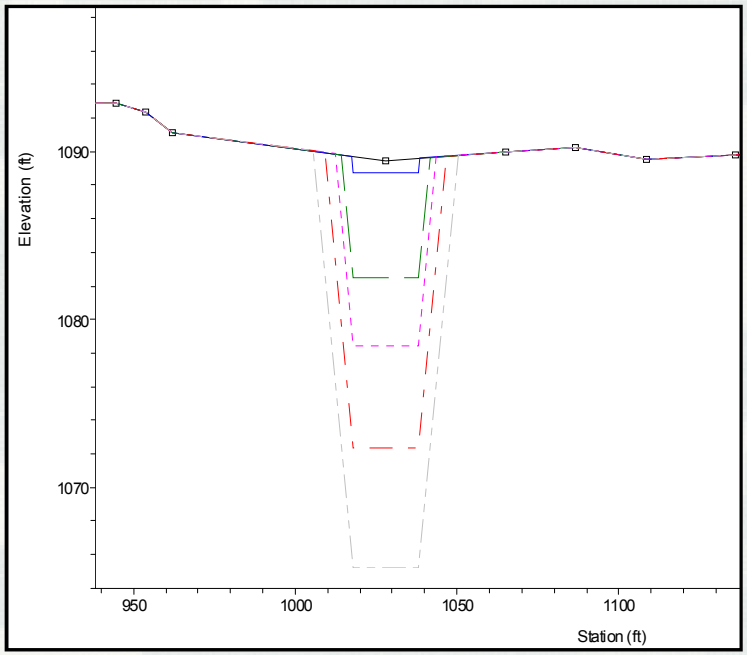




-Reservoir sediment erosion algorithms
-Reservoir stratigraphy capabilities
-New cohesive erosion algorithms

Springville Dam Removal Study





HEC-RAS XS Results
(Reservoir Sediment Erosion)

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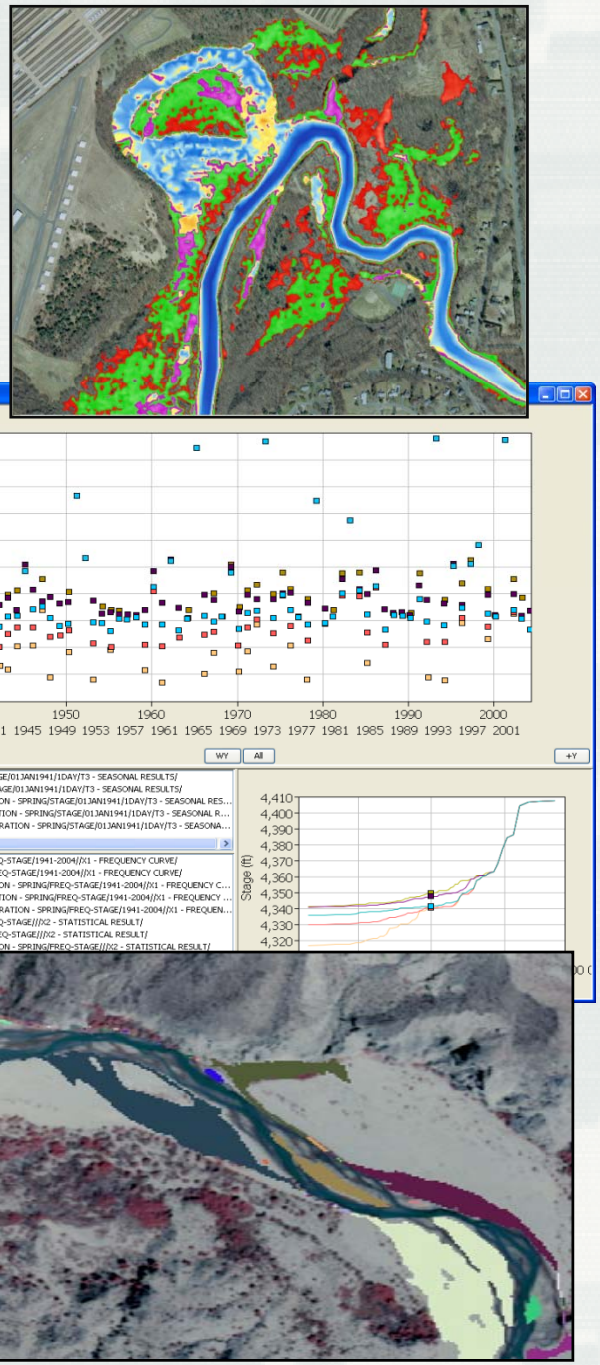
HEC-EFM

John Hickey

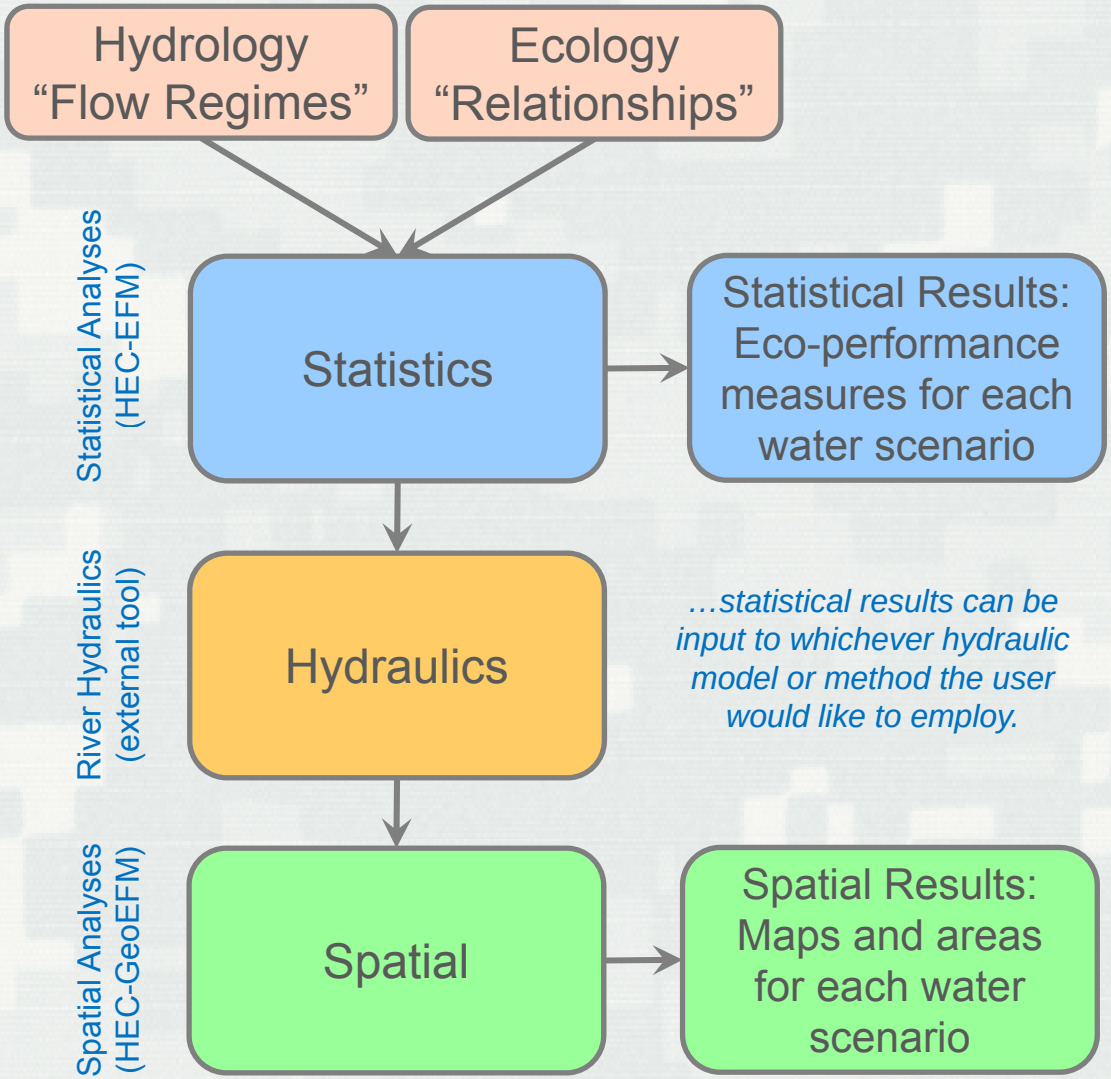
HEC-EFM

Ecosystem Functions Model

- Ecosystem responses to changes in hydrology
- Reservoir reoperations, diversions, reconfigure channels and levees, dam removal, climate change
  - Direction (+/-) and magnitude of changes → biological impact
  - Habitat changes in rivers and wetlands
  - Team use: biologists, hydrologists geomorphologists, hydraulic engineers, environmental managers
- Outputs: Eco-performance measures, habitat mapping, *population dynamics*



EFM - Stats and Habitat



EFM - Stats and Habitat

Hydrology "Flow Regimes"

Ecology "Relationships"

Statistical Analyses (HEC-EFM)

Statistics

Statistical Results: Eco-performance measures for each water scenario

River Hydraulics (external tool)

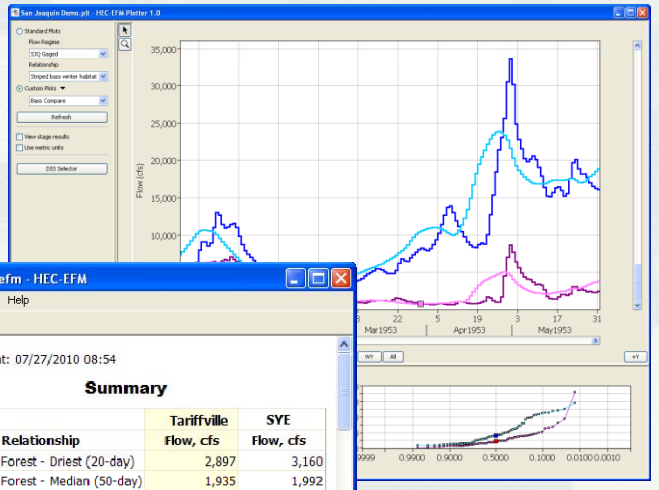
Hydraulics

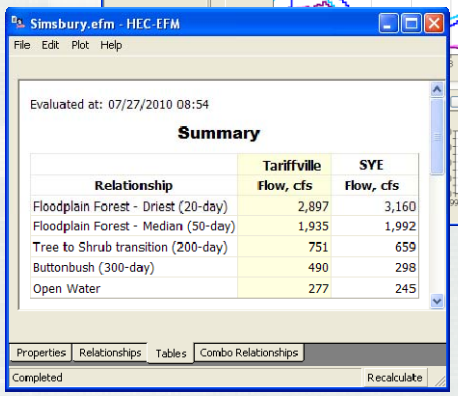
…statistical results can be input to whichever hydraulic model or method the user would like to employ.

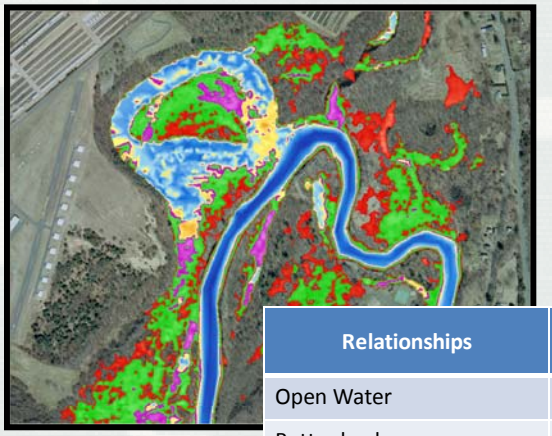
Spatial Analyses (HEC-GeoEFM)

Spatial

Spatial Results: Maps and areas for each water scenario



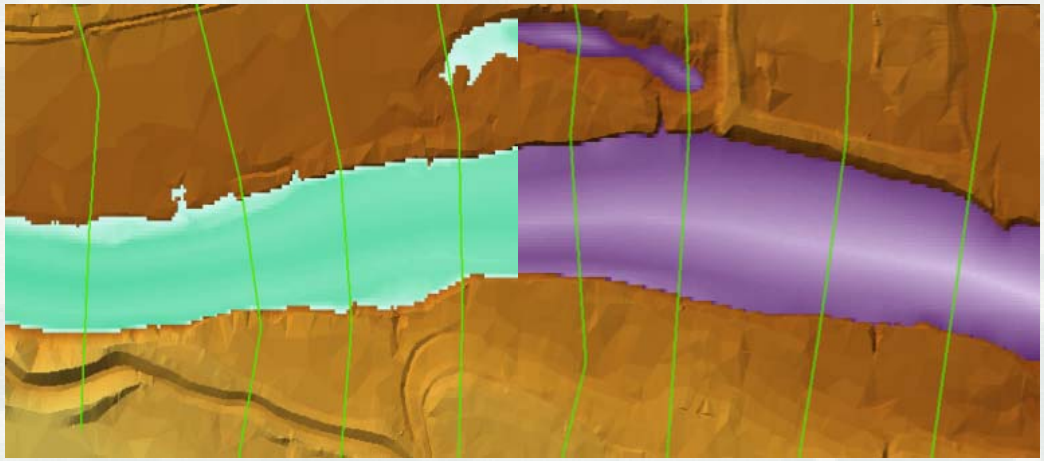


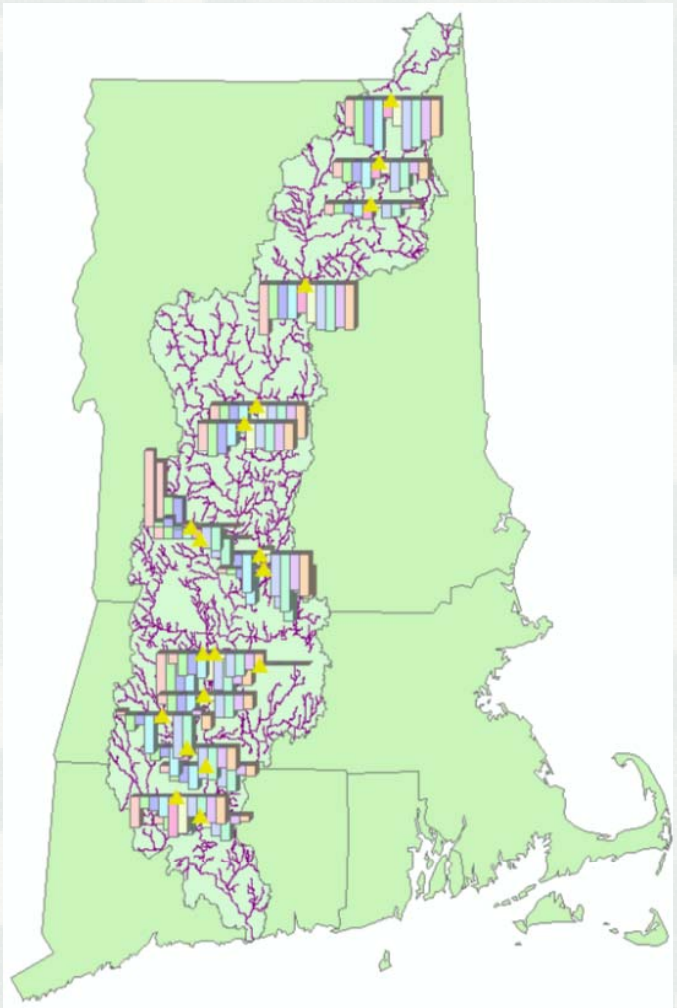


Relationships	Gaged (acres)	SYE (acres)
Open Water	196	184
Buttonbush	79	20
Mixed Shrubs	113	147
Floodplain Forest	762	842

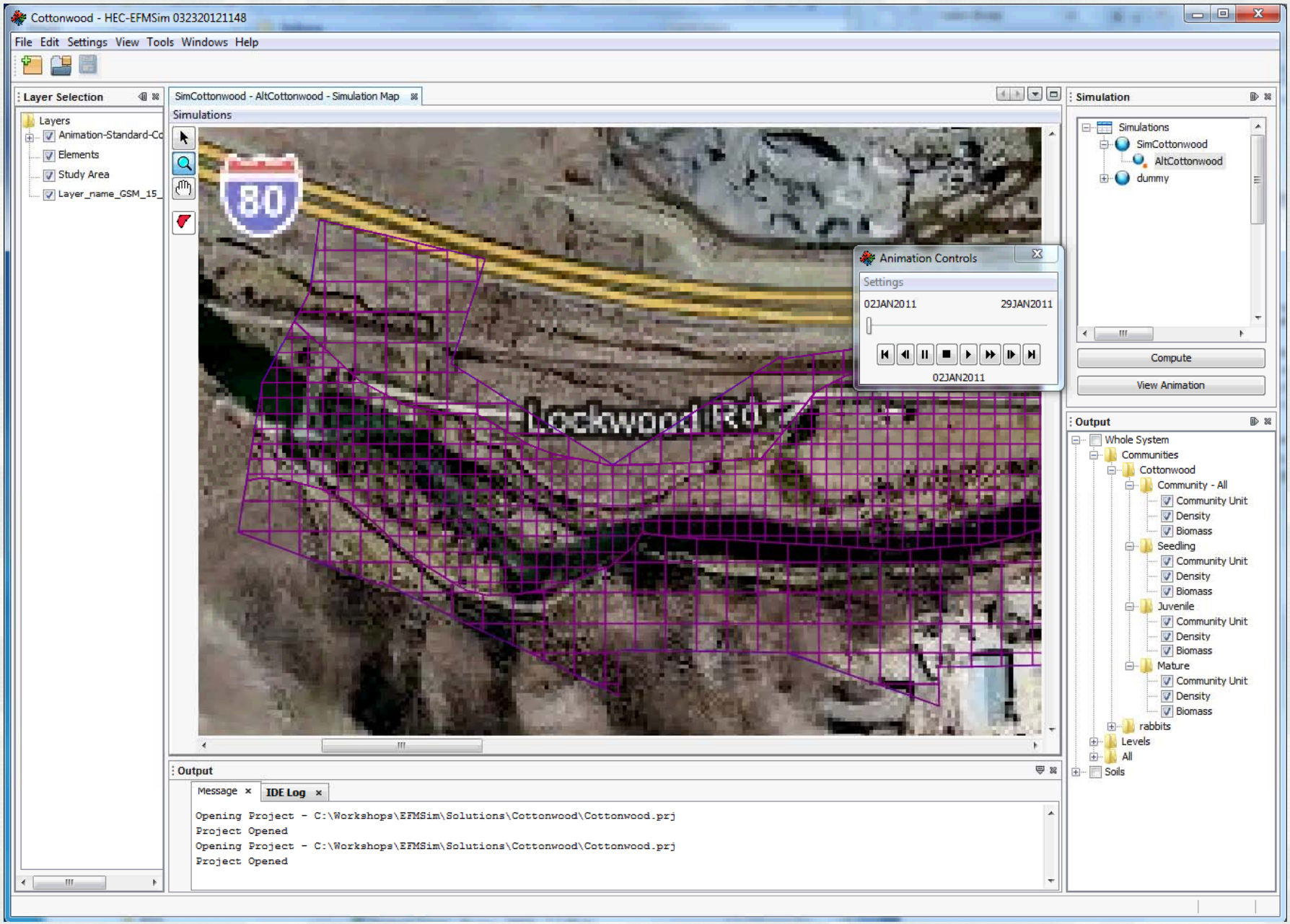
EFM - New Features

- Batch import of flow regimes
- Watershed-scale viewing of eco-performance measures
- Habitat map mosaics
- Habitat patches based on size and dimensions

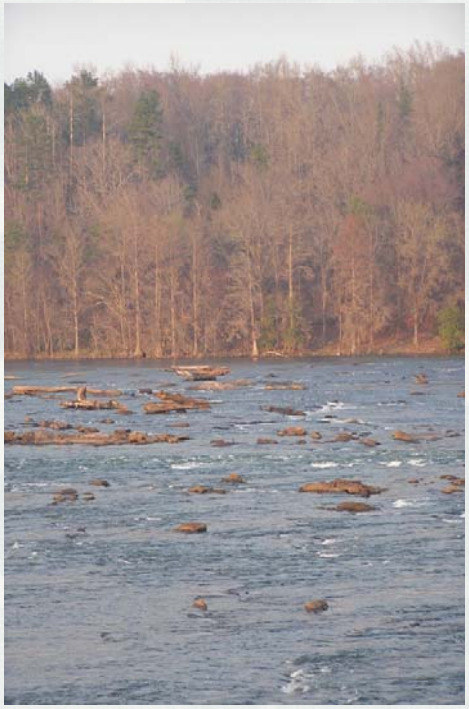




EFMSim - Population Dynamics



EFM Applications and Purposes…



- Farmington River, CT……..*Reservoir/ecosystem management*
- Sandy River Delta, OR……*Dam removal*
- Bill Williams River, AZ.....*Experimental flooding*
- Mississippi River, MO.....*Navigation pool operations*
- Truckee River, NV……..*River restoration*
- Ashuelot Rivers, NH……*Endangered species*
- Savannah River, GA/SC.....*Drought contingency planning*
- Sacramento/San Joaquin, CA.....*Ecosystem restoration planning*

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