Water Quality Modeling Capabilities for Application to Harmful Algal Bloom Management

Todd Steissberg, PhD, PE

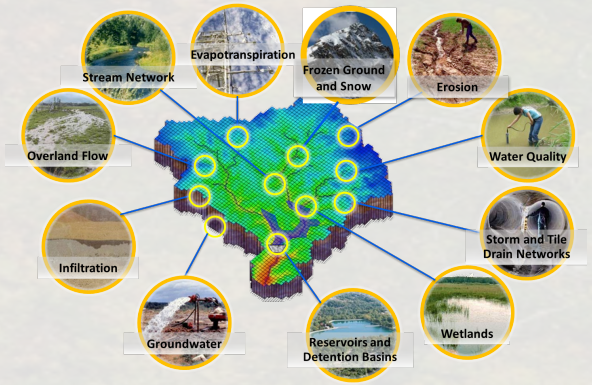
Environmental Laboratory
Water Quality and Contaminant Modeling Branch
U.S. Army Engineer Research and Development Center (ERDC)

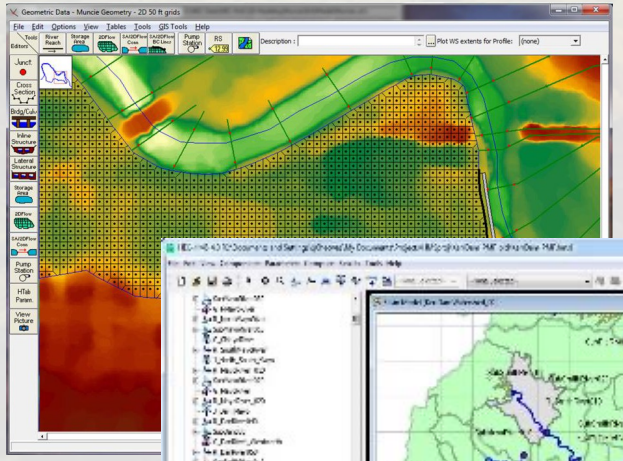
Harmful Algal Bloom Discussion

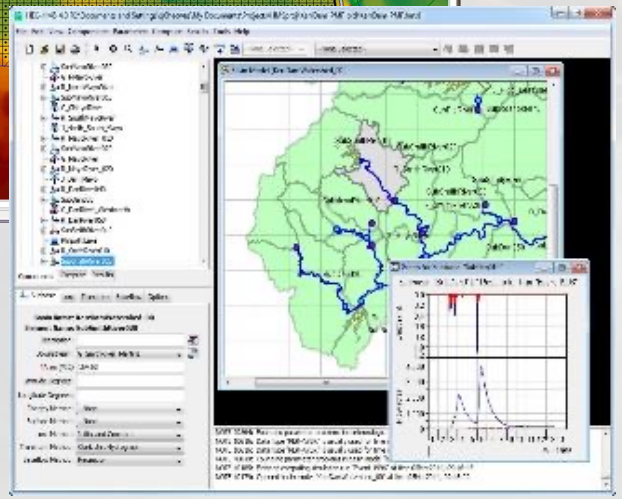
July 20, 2021

Water Quality Modeling Tools

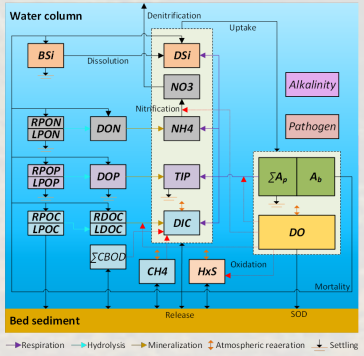
Hydraulics and Hydrology

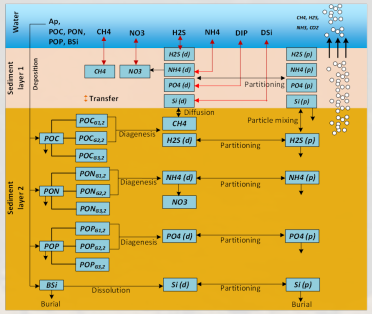


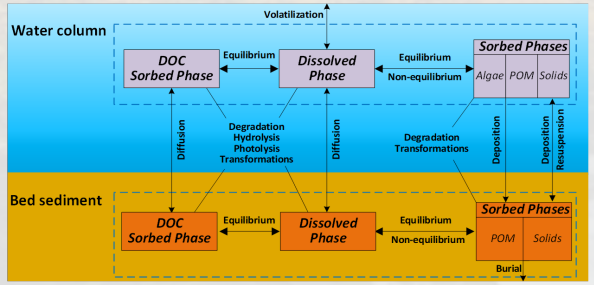


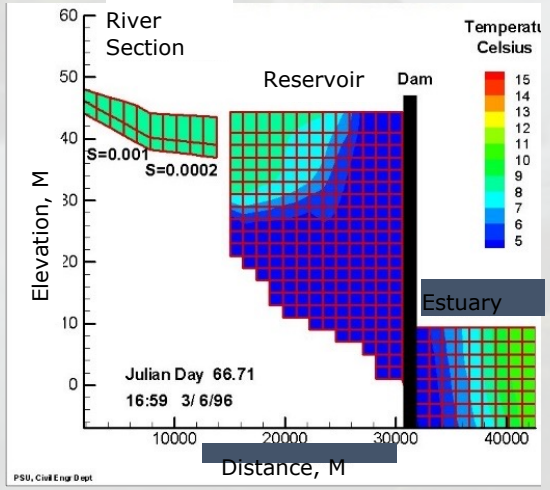


Water Quality

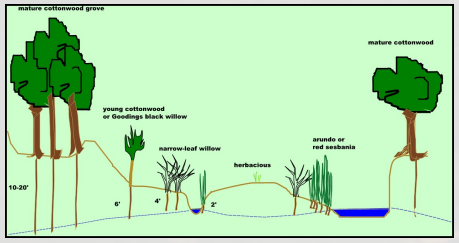


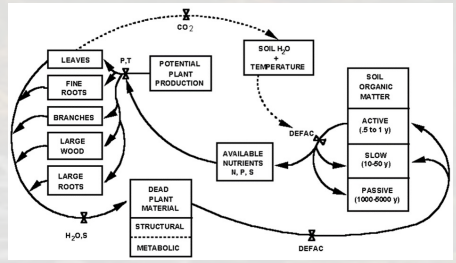


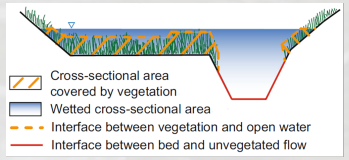




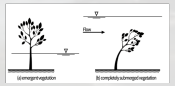
Vegetation







As Vegetation grows and dies, Hydraulic Roughness is allowed to change.



Design with Natural Features

Dallas, TX – Trinity River Project Includes:

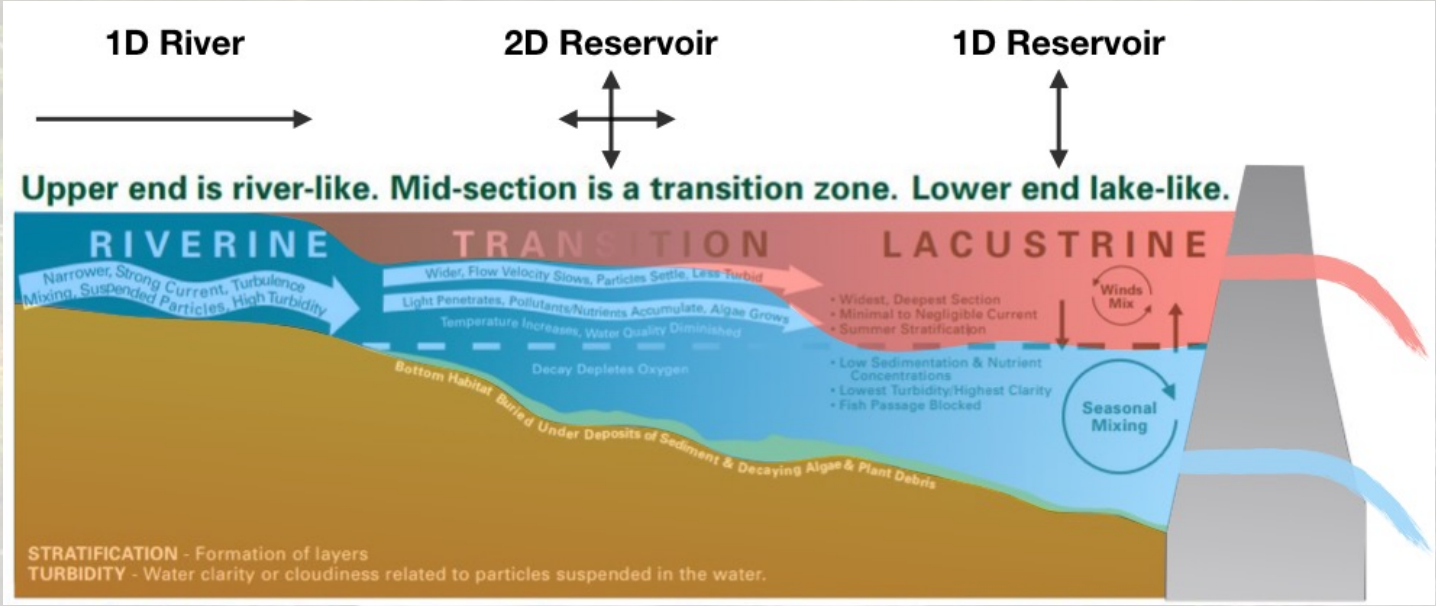
- River Channel modification / stream geomorphology
- Wetlands creation
- Park and trail planning
- Flood management
- Sediment management
- Corps permitting and levee management

Benefits of Water Quality Modeling

- Interpolation
  - Observed data is sparse in space and time
  - Answer questions like:
    - Where are the best locations for sampling?
    - Where are the most severe water quality problems occurring?
- Extrapolation
  - Forecast WQ in the future
  - Predict WQ for different water management scenarios
  - Answer questions like:
    - How will the ecosystem function in the future given the current set of conditions?
    - How will the watershed function under different climate forcing conditions?
    - How will the ecosystem respond if flow allocations are changed, hydropower withdrawals are increased, and releases are altered to meet ecosystem restoration targets (e-flows)?
- Improve understanding of the system

Reservoir Processes and Zones

- Riverine zone
  - River-like flows within channel
  - Minimum requirement: 1D river model (segments)
- Lacustrine zone
  - Lake-like system, vertically stratified, slow flows
  - Minimum requirement: 1D reservoir model (layers)
- Transition zone
  - Stratification and downstream flows important
  - Minimum requirement: 2D model (layers and segments)



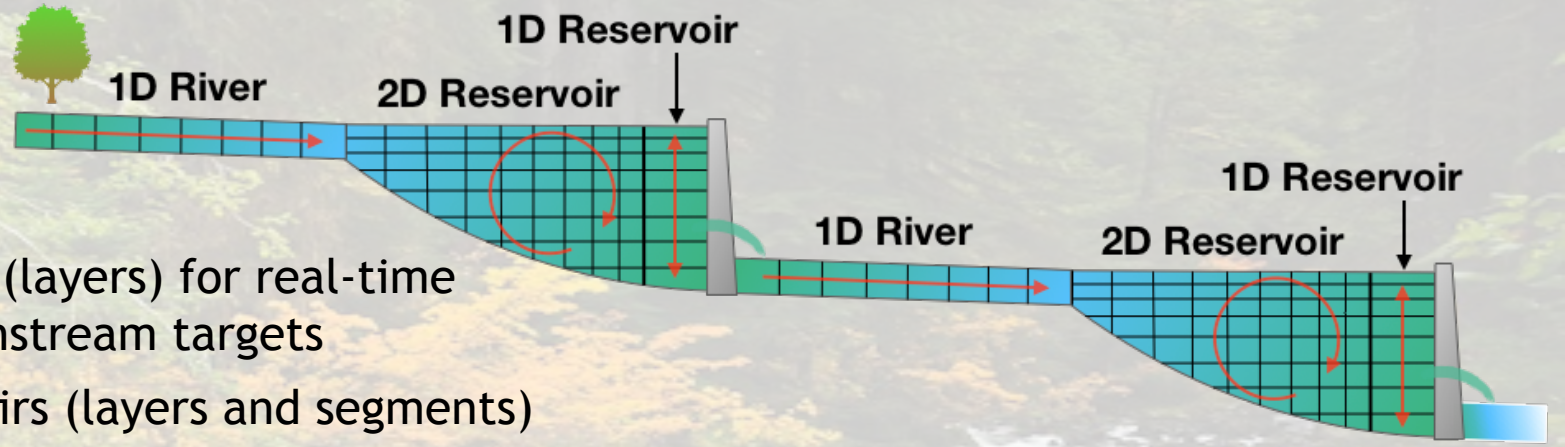
Reservoir system with important flow, WQ, and ecosystem processes for each of three zones.

Notes:

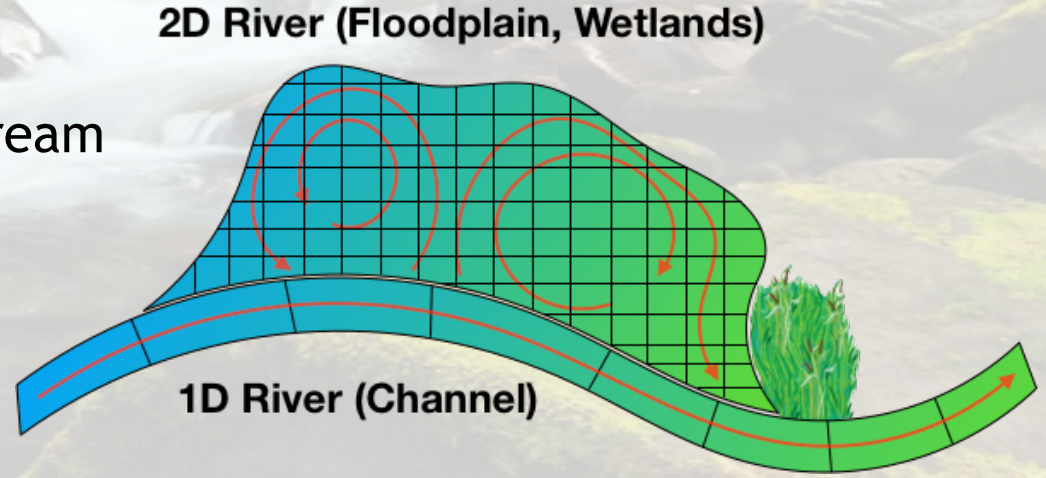
- 1D river model for channels in a reservoir system
- 2D river model for floodplain simulation

River and Reservoir WQ Modeling and Dimensions

- River-Reservoir System (stratification important)
  - Unstratified reaches:
    - Modeled as 1D rivers (segments)
  - Stratified reaches:
    - Can be modeled as 1D reservoirs (layers) for real-time release decision-making for downstream targets
    - Should be modeled as 2D reservoirs (layers and segments)
      - Ensure accuracy, capturing important in-reservoir processes (mixing, pollutants inflows, etc.)
      - Identify vulnerabilities and restoration/management options (e.g., velocities and temperature for HAB management)

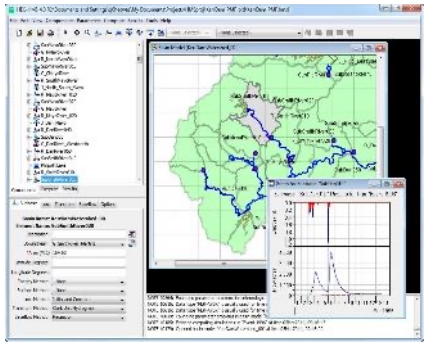


- River-Floodplain System (unstratified)
  - River channels are modeled as 1D, varying from upstream to downstream
  - Hydrologic connectivity across the floodplain is important
    - 2D varying across the landscape



Integrated Watershed Water Quality Modeling

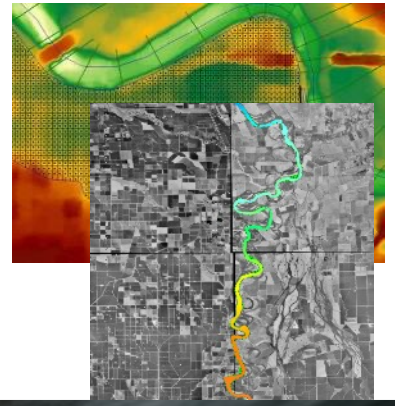
HEC-HMS
Runoff

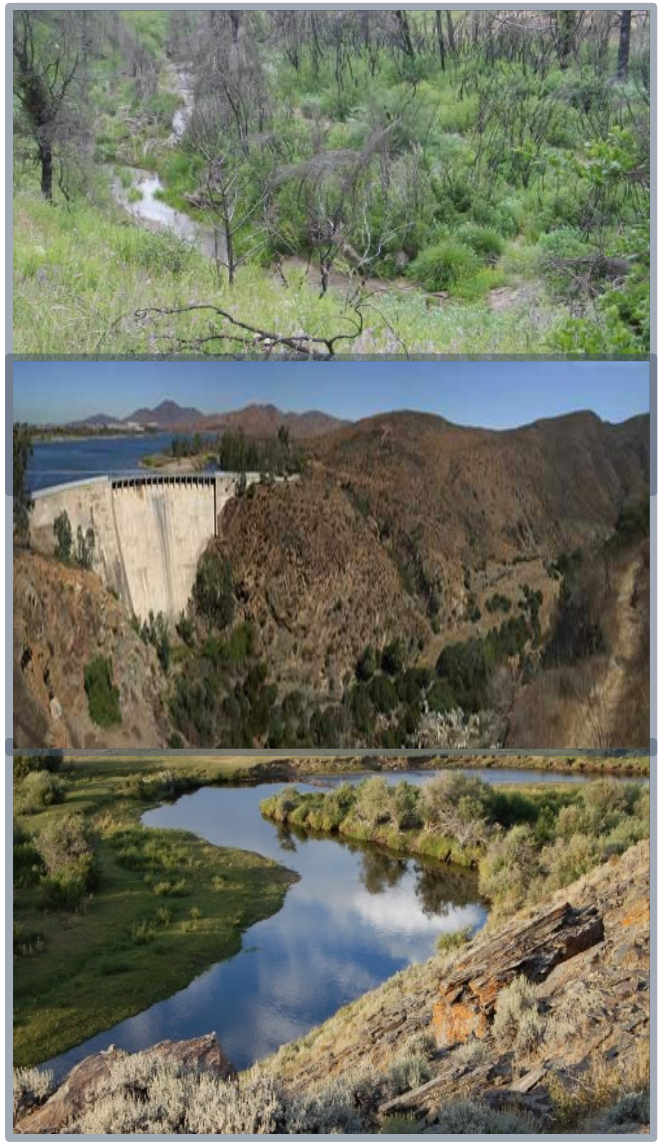


HEC-ResSim
Reservoir release decisions

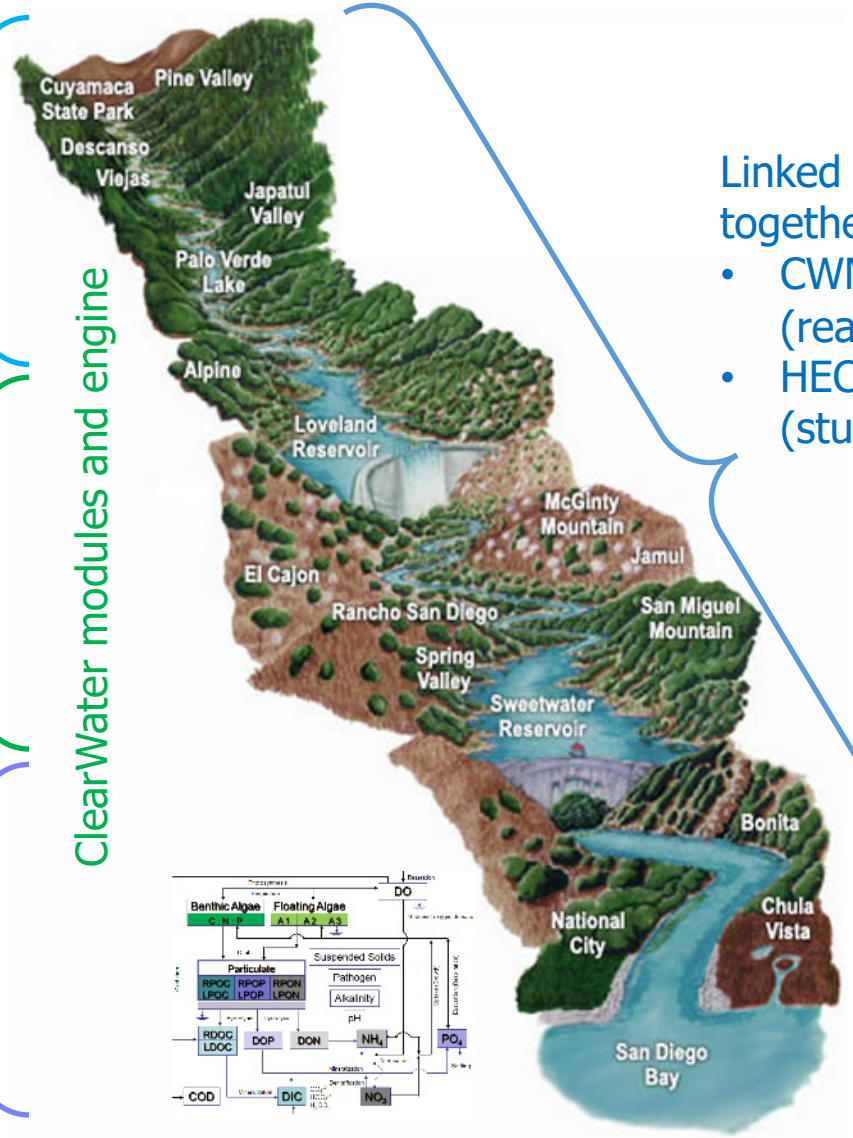
CE-QUAL-W2
2D Reservoir WQ

HEC-RAS
River hydraulics





ClearWater modules and engine



Linked together with

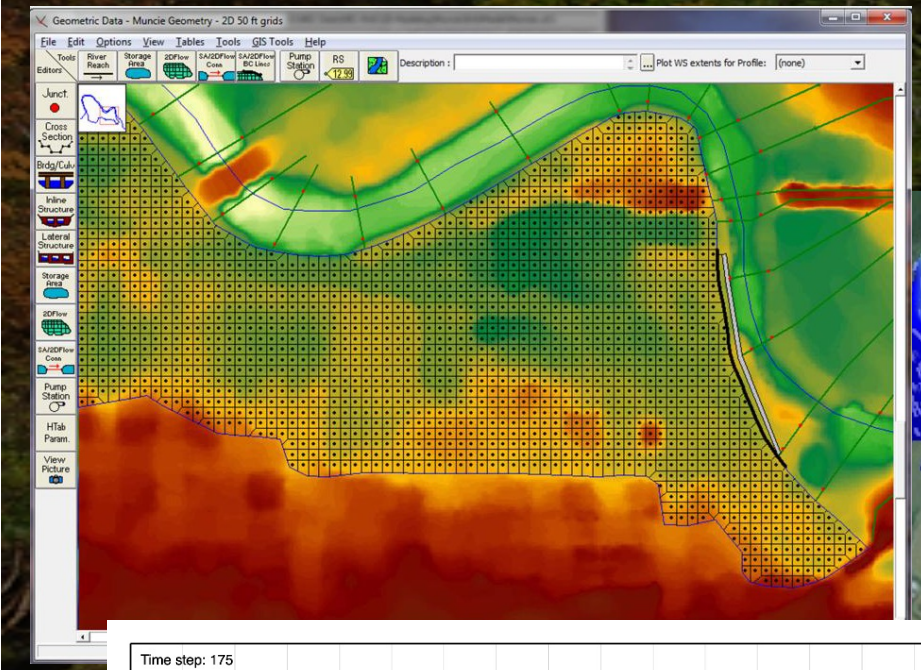
- CWMS (real-time)
- HEC-WAT (studies)

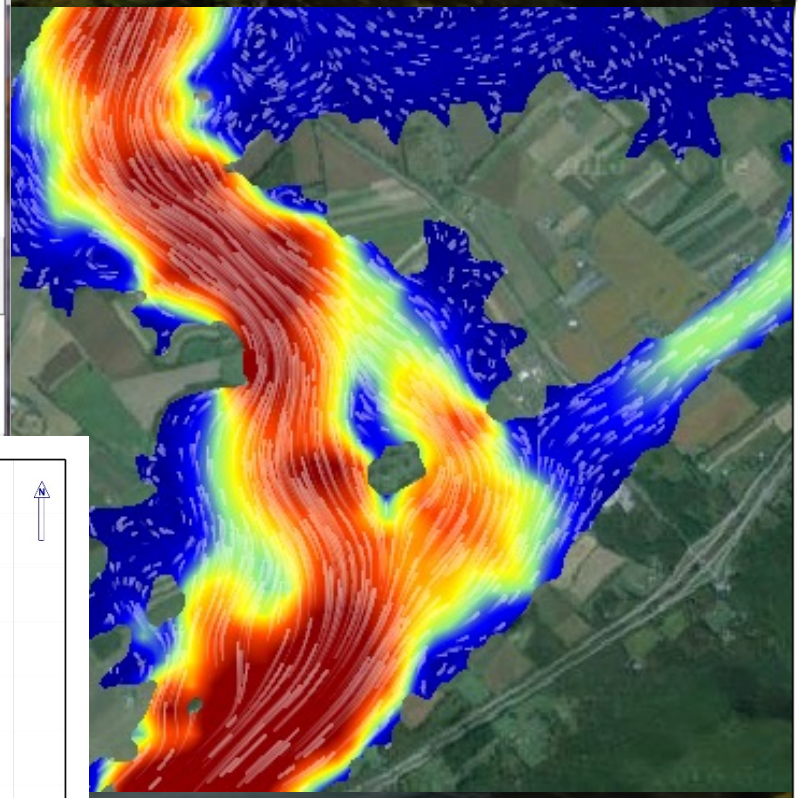
Water Quality and Ecological Modeling Capabilities

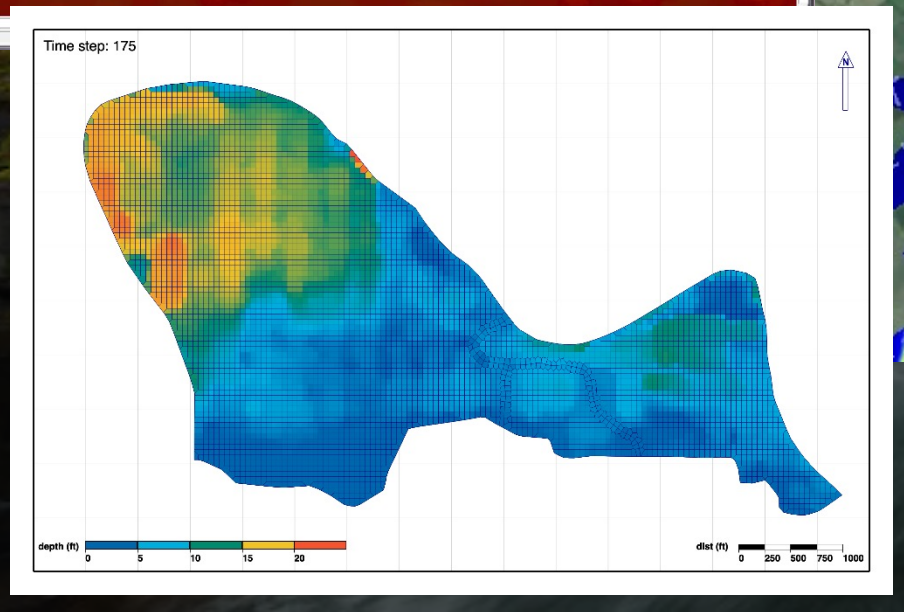
- ClearWater (Computational Library for Environmental Analysis and Restoration of Watersheds) is a computational library that is being embedded in existing water resources simulation models.
  1. Modules that simulate water temperature, chemical reactions and transformations, and riparian vegetation. These modules are:
     - NSM: Nutrient Simulation Module
     - TSM: Temperature Simulation Module
     - MSM: Mercury Simulation Module
     - CSM: Contaminant Simulation Module
     - SSM: Solids Simulation Module
     - RVSM: Riparian Vegetation Simulation Module
       - VSM: Vegetation Simulation Module (1D/2D riparian and aquatic vegetation)
  2. A water quality engine that computes the transport processes and integrates the Clearwater modules with the water resources simulation program (e.g., HEC-ResSim)
  3. Graphical User Interface (GUI) components for WQ modeling:
     - Controls and tables to input/import set up a WQ model
       - Boundary & initial conditions, variables, parameters, etc.
     - Plots
     - Reports

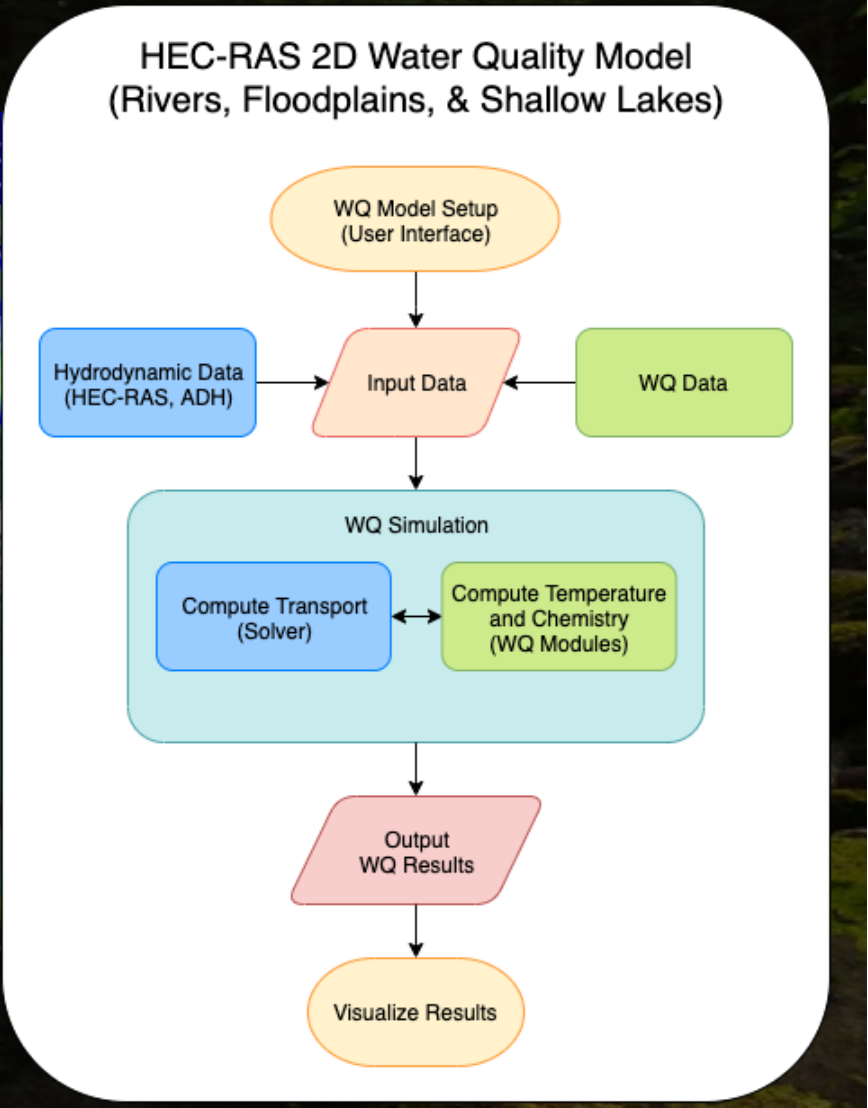
HEC-RAS - 2D Water Quality

Two-Dimensional (2D) Depth-Averaged Water Quality









HEC-RAS RVSM – Jupyter Notebook

jupyter RVSM_Notebook Last Checkpoint: 11 minutes ago (autosaved) Logout

File Edit View Insert Cell Kernel Widgets Help Trusted Python 3

Run Markdown

ERDC

Riparian Vegetation Simulation Module (RVSM)

October 1, 2020

Step 1. Set up HEC-RAS river hydraulics model

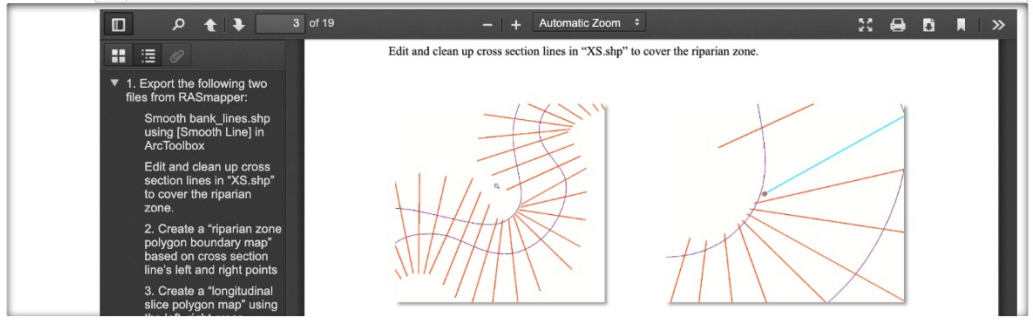
- Download HEC-RAS, Version 6.0
- HEC-RAS User's Manual

In [1]:
```
# Import functions
%run RVSM_CODE.ipynb
```

Step 2. Delineate vegetation polygons

- Export river cross-sections from the HEC-RAS model
- Import cross-sections into ArcGIS
- Draw vegetation polygons to delineate the boundaries of each vegetation type
- Export the polygons to ASCII tables
- Detailed instructions are found in the following document:

In [2]:
```
display(vegetation_polygons)
```



If the PDF above is blank or displays only one page:

- Add the PDF Chromium extension, if you are using Chrome or Opera.
- Open the PDF in an external viewer.
- Uncomment the function below to open the PDF.

In [3]:
```
#show_vegetation_polygon_delineation_pdf()
```

Step 3. Set paths to HEC-RAS vegetation polygon folders

In [4]:
```
set_paths();
```

HEC-RAS Executable: C:/Program Files (x86)/HEC/HEC-RAS/6.0/Ras.exe

HEC-RAS Project Folder: C:/Users/usr/Documents/HEC Data/HEC-RAS/projname

Vegetation Polygon Folder: C:/Users/usr/Documents/RAS_RVSM/Veg_Poly

Step 4. Run or debug HEC-RAS-RVSM

In [5]:
```
run_hec_ras();
```

Run HEC-RAS-RVSM

Debug HEC-RAS-RVSM

More information on Jupyter Notebooks and JupyterLab can be found at:

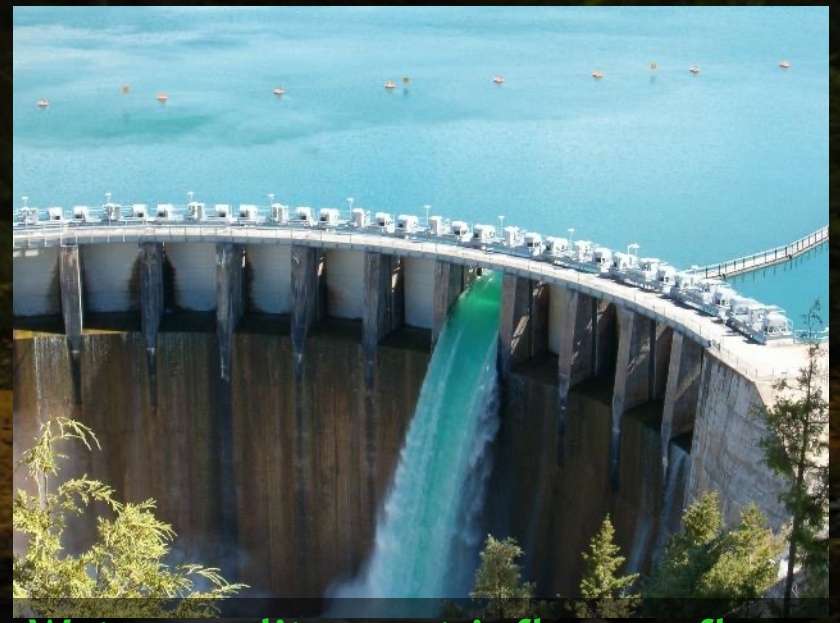
- Jupyter Notebook
- JupyterLab

See the following for information on the Python programming language and its wide array of scientific and visualization libraries:

- Python
- SciPy
- Matplotlib
- Pandas
- NumPy

HEC-ResSim Water Quality

Flows influence water quality

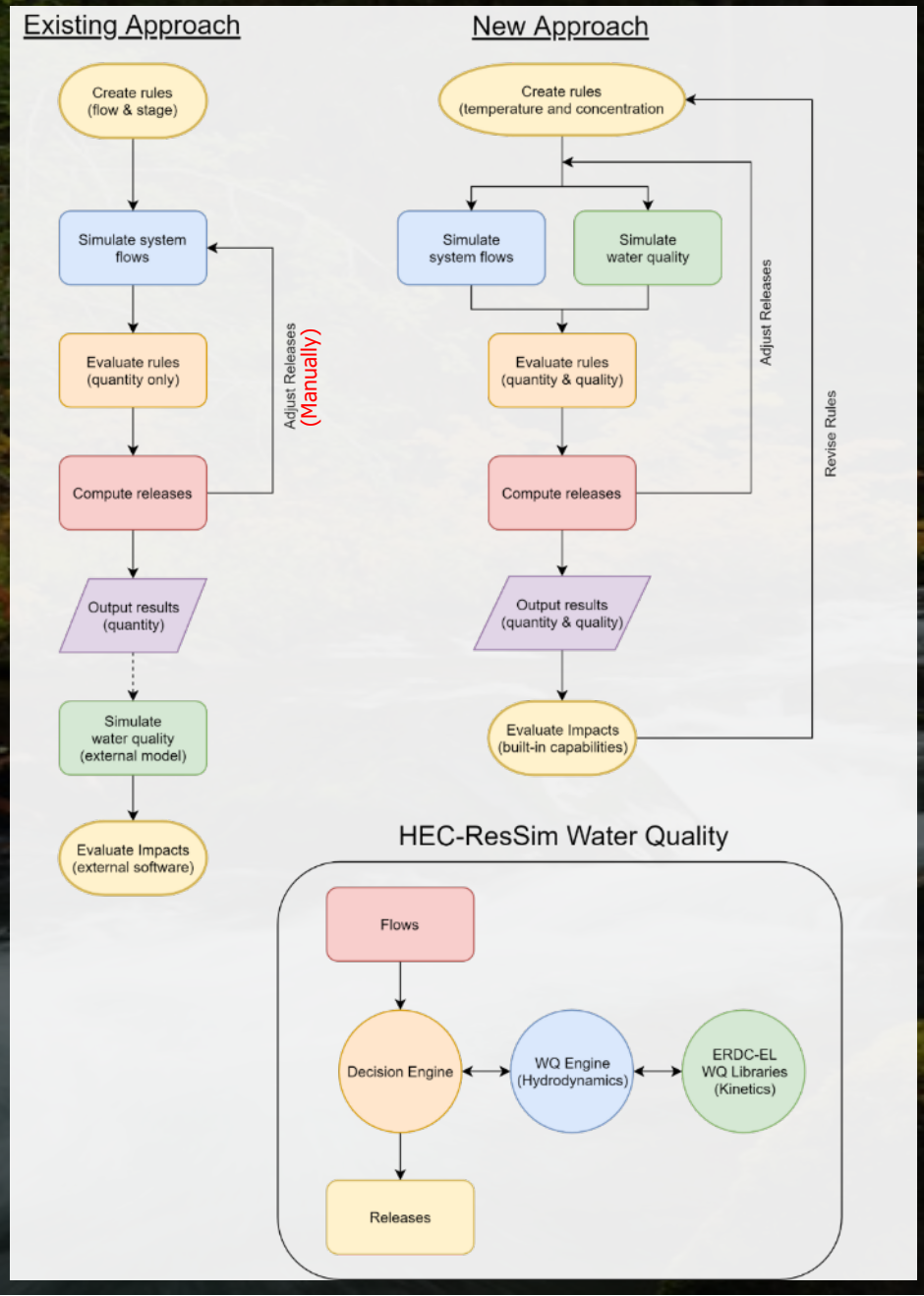


Water quality must influence flows

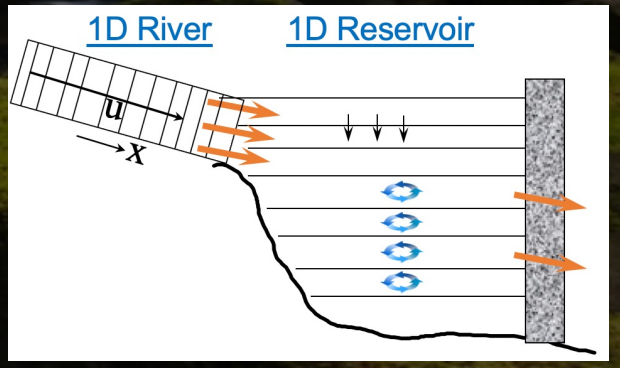
- Problem: Currently, water quality modeling is performed separately from reservoir operation decision-making, with results being laboriously transferred between models, requiring repeated adjustments and recomputations to achieve environmental project objectives. Environmental considerations are not directly accounted for in reservoir operations decision-making, since existing reservoir water quality models cannot continuously inform reservoir operations models about how much water should be released meet these requirements.
- Purpose: Integrate water quality modeling capabilities into HEC-ResSim so that water quality and related environmental objectives can directly influence reservoir release decision-making, and provide capabilities for watershed-scale ecosystem assessment and management.

HEC-ResSim Water Quality

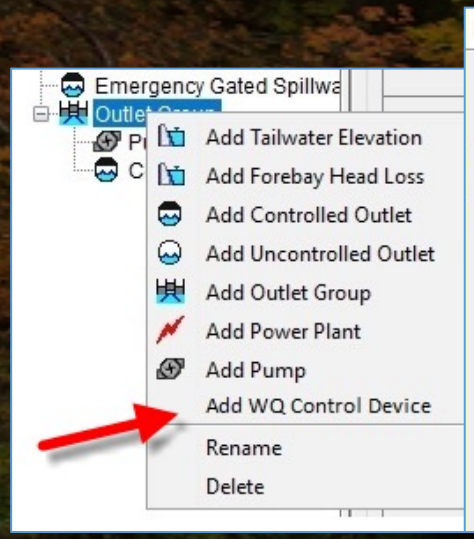
- Existing Approach
  - WQ is simulated with an external model (e.g., HEC-5Q) after the HEC-ResSim flow simulation is complete.
  - Rules are specified in terms of stage or flow.
  - Environmental objectives are often lumped in with other objectives, such as navigation, flood control, or hydropower.
  - If the desired environmental benefits of an alternative are not achieved, new guesses must be made, and the simulation recomputed. This stage is often skipped altogether.

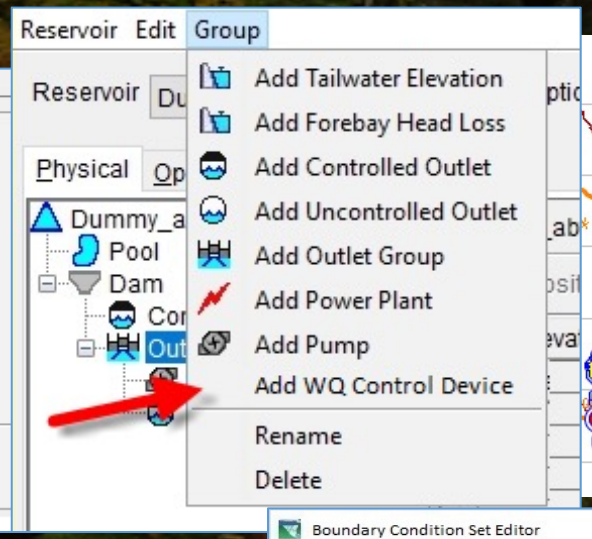


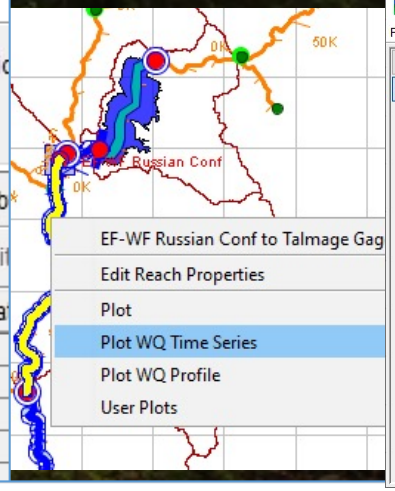
- New Approach
  - WQ runs in parallel with the system hydrology and release decisions
  - Reservoir operation rules can be specified directly (i.e., temperature, concentration, or load) to meet environmental objectives
  - Project teams will have the opportunity to define rules for environmental objectives independent of other objectives

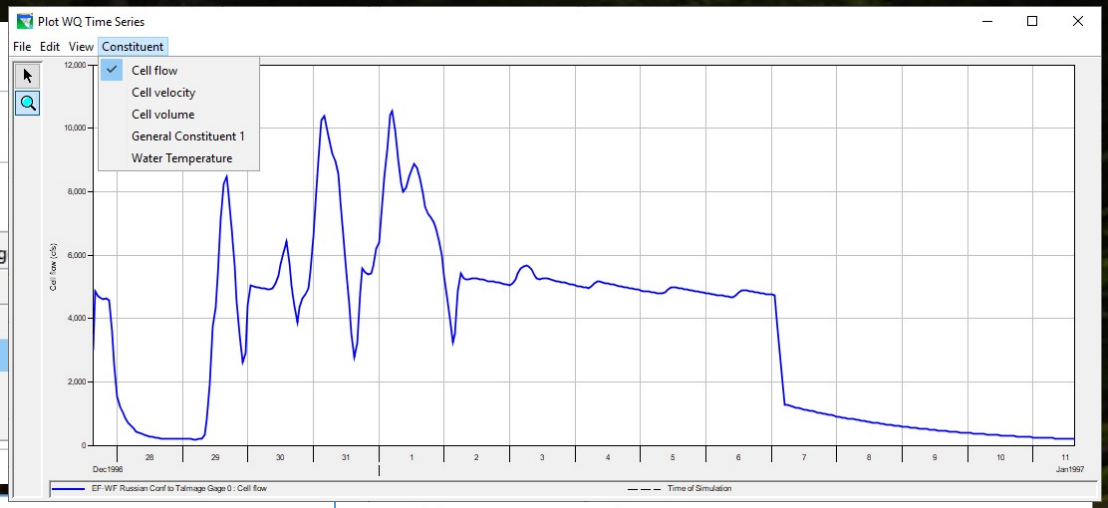


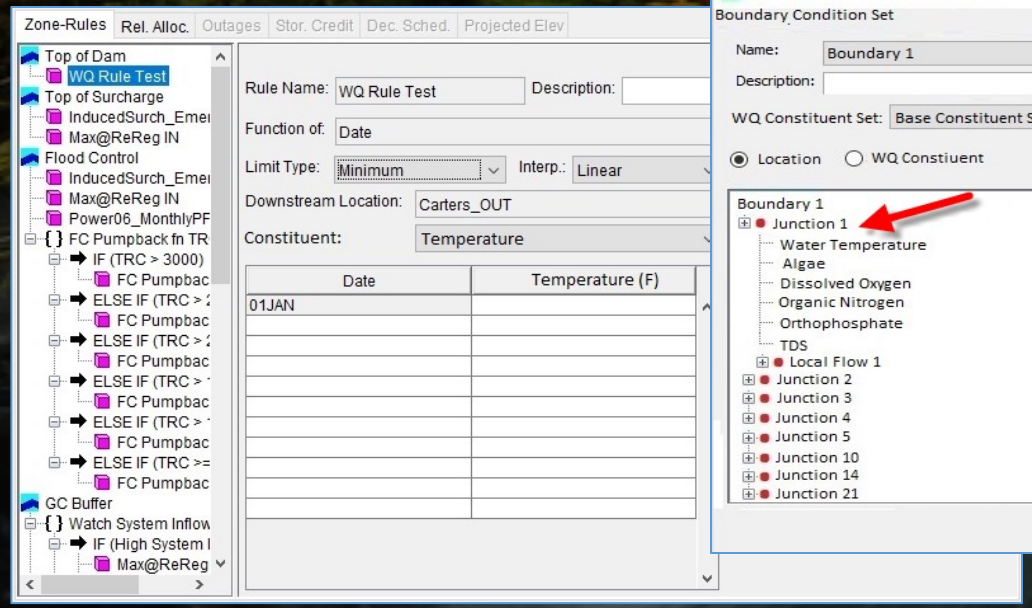
HEC-ResSim v4.0

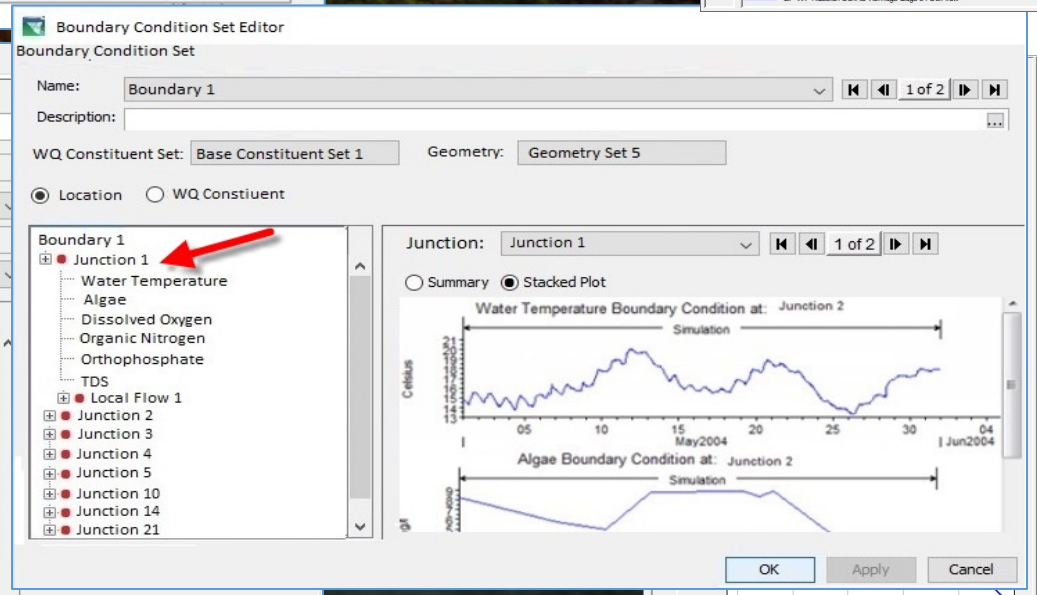


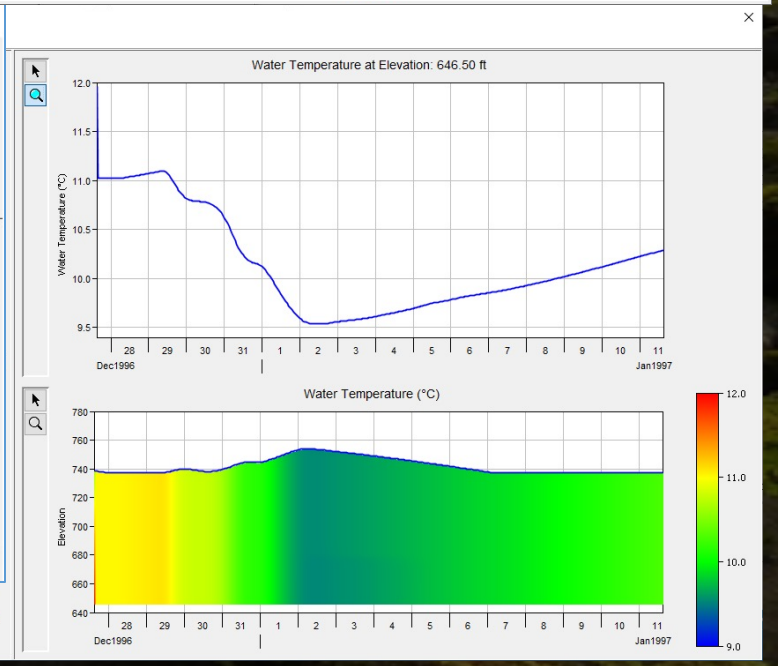








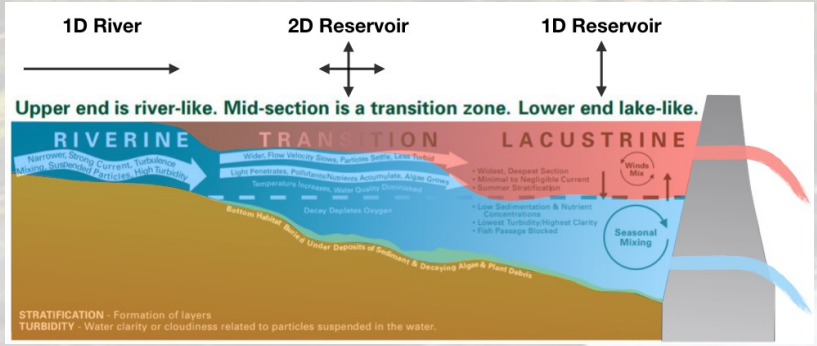


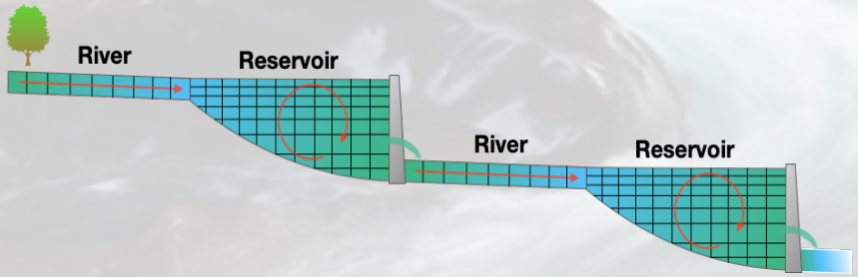


Development of New Capabilities and Enhancements to the USACE Two-Dimensional Reservoir Water Quality Model (CE-QUAL-W2)

Problem Statement

USACE needs an improved version of CE-QUAL-W2 capable of performing integrated watershed-scale water quality modeling that supports multi-objective decision-making. The current version lacks critical features that would allow multiple W2 models to be seamlessly and efficiently integrated with other models and data into current modeling systems being utilized by USACE districts.

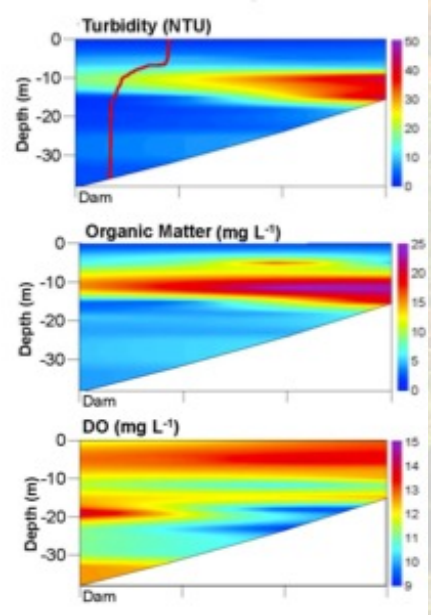




Technical Approach

- Upgrade water quality kinetics
  - Incorporate full carbon cycle with N and P cycles
  - Reformulate BOD group simulations
  - Incorporate sediment diagenesis module
- Upgrade model input and output
  - Support modern open-source formats: HDF5, JSON, CSV
- Develop Python/Jupyter model framework and plotting capabilities
  - Python libraries to handle I/O
  - Jupyter notebook interface
  - Plotting capabilities: time series, bathymetry, 2D contour plots
- Develop multi-objective reservoir operation capabilities
  - Incorporates environmental objectives into the decision-making process
- Upgrade hydrodynamic and water quality engine
  - Improve computational efficiency
  - Improve stability
  - Improve selective withdrawal algorithm
- Deliver CE-QUAL-W2 v5.0 with documentation
  - User's manual
  - Technical reference manual

Development of New Capabilities and Enhancements to the USACE Two-Dimensional Reservoir Water Quality Model (CE-QUAL-W2)



Value to the Nation

CE-QUAL-W2 v5.0 will support the Corps' need for environmental assessment, restoration, and management. Its reservoir operations capabilities will enable accurate determination of the decisions that effectively achieve environmental objectives. Critical downstream habitat will be better managed for water quantity (volume, velocity, depths, etc.) as well as water quality objectives (water temperature, dissolved oxygen, total dissolved gas, etc.).

Deliverables by Year

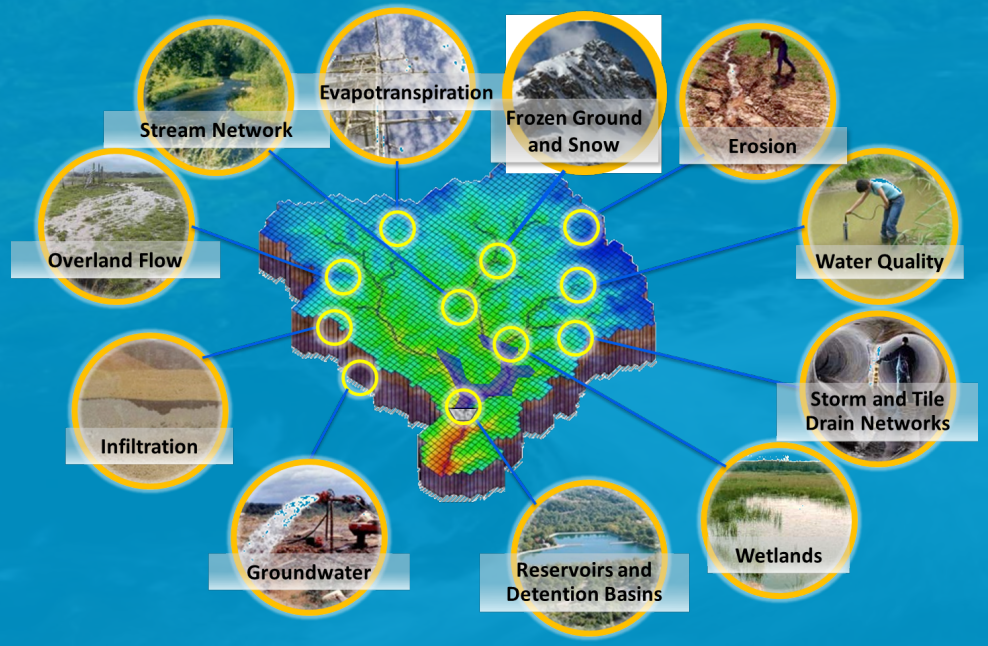
- CE-QUAL-W2 v4.3 – 4Q FY21
- Python framework & reservoir operations capability for v5.0 – 4Q FY21
- CE-QUAL-W2 v5.0 Alpha – 2Q FY22
- CE-QUAL-W2 v5.0 Final and Tech Transfer – 4Q FY23

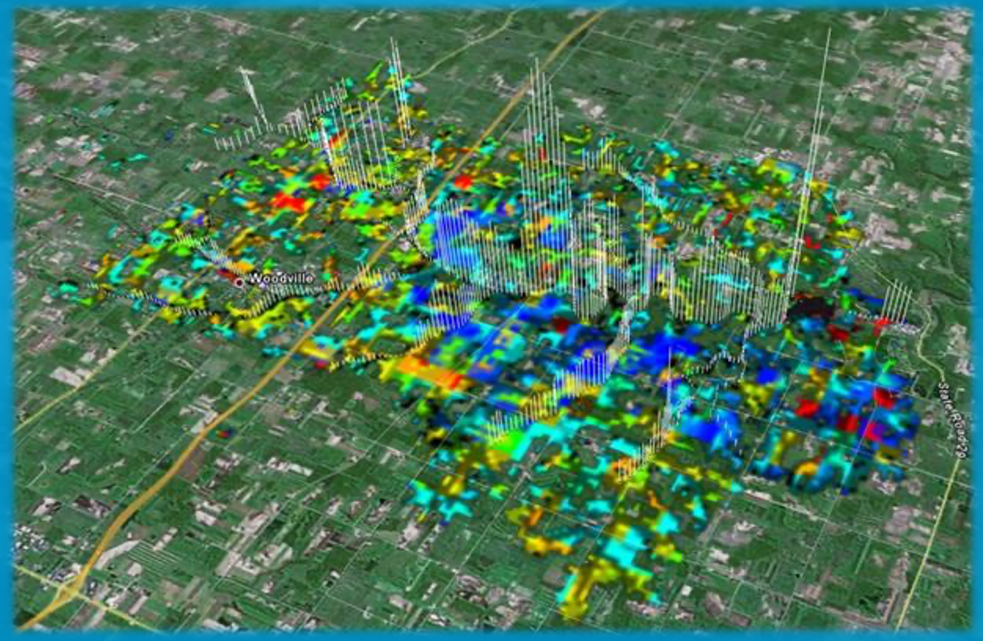
	Qtr1	Qtr2	Qtr3	Qtr4
FY21				W2 v4.3, v5.0 components
FY22		W2 v5.0 Alpha		
FY23				W2 v5.0, Documentation, TN, Webinar

Watershed Runoff Water Quality Modeling

GSSHA Water Quality and Vegetation

- The ERDC Environmental Laboratory (EL) and Coastal and Hydraulic Laboratory (CHL) are collaborating through the Ecofutures project to link water quality and vegetation (aquatic and terrestrial) modeling capabilities with the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) program.
- The new capabilities will enable simulation of the surface and sub-surface flow of heat and nutrients in ecosystems at watershed scales.





Team Members and Contributors
(Alphabetical)

- Lea Adams, USACE-HEC
- Marriah Abellera, USACE-IWR
- Anthony Aufdenkampe, LimnoTech
- Steve Andrews, RMA
- Chris Berger, PSU
- Tom Brauer, USACE-HEC
- Barry Bunch, USACE-ERDC-EL
- John DeGeorge, RMA
- Tim Dekker, LimnoTech
- Mark Dortch, ERDC-EL
- Chris Dunn, USACE-HEC
- Paul Ely, RMA
- Scott English, USACE-NWD
- Trudy Estes, ERDC-EL
- Matt Fleming, USACE-HEC
- Joan Klipsch, USACE-HEC
- John Kucharski, USACE-ERDC-EL
- Mark Jensen, USACE-HEC
- Billy Johnson, USACE-ERDC-EL
- Lora Johnson, USACE-ERDC-EL
- Shannon Larson, RMA
- Cindy Lowney, RMA
- Ryan Miles, RMA
- Shannon Newbold, RMA
- Jennifer Olszewski, USACE-ERDC-EL
- Leila Ostadrahimi, USACE-HEC
- Jay Pak, USACE-HEC
- Greg Peterson, LimnoTech
- Steve Piper, RMA
- Daniel Rucinski, LimnoTech
- Jason Rutyna, LimnoTech
- Jodi Ryder, USACE-ERDC-EL
- Alex Sanchez, USACE-HEC
- Tad Slawecki, LimnoTech
- Don Smith, RMA
- Julia Slaughter, USACE-HEC
- Todd Steissberg, USACE-ERDC-EL
- Kathryn Tackley, USACE-NWP
- Tammy Threadgill, USACE-ERDC-EL
- Dottie Tillman, USACE-ERDC-EL
- Dan Turner, USACE-NWD
- Scott Wells, Portland State University
- Brian Zettle, USACE-SAM
- Zhonglong Zhang, Portland State University


Thank You!
Questions?