Integrating Natural Processes and Features into Watershed Modeling

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Water Quality Modeling Team

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Integrated Environmental Modeling Tools

Hydraulics & Hydrology
- River networks
- Wetlands
- Inundation

Water Quality
- Water column
- Dissolved Oxygen
- Nutrients (N, P)

Vegetation
- Tree growth
- Wetland ecosystems

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
Integrated Watershed Water Quality Modeling

Linked together with:
- CWMS (real-time)
- HEC-WAT (studies)

HEC-HMS Runoff
HEC-ResSim Reservoir release decisions
HEC-RAS River hydraulics

Clearwater modules and engine
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
  • 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
      o Boundary & initial conditions, variables, parameters, etc.
    • Plots
    • Reports
Vision: Environmental Modeling with HEC Tools

• The U.S. Army Corps of Engineers’ Water Quality Modeling Team is developing next-generation water quality modeling and analysis capabilities by integrating independent water quality modules with existing water resource modeling software. The team consists of staff from ERDC, HEC, USACE Districts, and other organizations. An ERDC-HEC partnership was established to develop water quality modeling capabilities for three widely used water resources modeling programs developed by the Hydrologic Engineering Center. These are:
  • HEC-ResSim (Reservoir System Simulation): simulates reservoir operations for one or more reservoirs for flood management, planning studies, real-time decision support, and many other purposes.
  • HEC-RAS (River Analysis System): simulates river hydraulics, computing water levels and velocities, and generates inundation (flood) maps
  • HEC-HMS (Hydrologic Modeling System): simulates runoff from the watershed
• HEC models have been built for most of the watersheds in the U.S. and for many of the watersheds in other countries. The water quality capabilities being developed for the HEC software leverages these models and existing software capabilities distribute advanced water quality modeling capabilities around the world. These will be linked, leveraging the strengths of each model to perform integrated watershed-scale water quality modeling for ecosystem assessment, restoration, and management.
HEC-RAS
River Water Quality (1D)

- HEC-RAS (River Analysis System) simulates 1D and 2D river hydraulics
  - Computes river velocities, stages, profiles, and inundated areas (with RAS Mapper) given stream flow and geometry
- Industry standard hydraulic tool used worldwide
- 100,000 worldwide downloads/year
- One-dimensional (1D) water quality capabilities allow environmental impacts assessments in rivers and streams
The Riparian Vegetation Simulation Module (RVSM) simulates the lifecycle of vegetation, including seed dispersal, seedling establishment, and plant growth and mortality in response to dynamic physical conditions.

- RVSM includes eleven vegetation roughness computation methods.

Hydrologic Processes:
HEC-RAS Riparian Vegetation Simulation

• RVSM was integrated into HEC-RAS to simulate the interactions between flow and riparian vegetation on floodplains.

• RVSM can help answer the following questions:
  • What impact does riparian vegetation have on local flood conditions?
  • What set of riverine operations can be used to encourage recruitment and survival of native vegetation (and control the spread of invasive species)?
  • What impact will management actions have on habitat for endangered and threatened species?

• For each time step:
  • HEC-RAS computes water surface elevation, discharge, average velocity, energy slope of each cross section.
  • RVSM simulates the impacts of these variables on the riparian vegetation lifecycle and computes the impacts of riparian vegetation on channel roughness (Manning’s n values).
  • The new roughness values replace the previous values in the HEC-RAS model and are used to compute new hydraulic variables for the next time step.
HEC-RAS Riparian Vegetation Simulation

• Application:
  • The riparian zone needs to be discretized into a vegetation computation mesh, including an array of parallel slice polygons along the channel bank.

• HEC-RAS schematic with vegetation polygons:
HEC-RAS - 2D Water Quality
Two-Dimensional (2D) Depth-Averaged Water Quality

HEC-RAS 2D Water Quality Model
(Rivers, Floodplains, & Shallow Lakes)

- WQ Model Setup
  (User Interface)

- Input Data

- Hydrodynamic Data
  (HEC-RAS, ADH)

- WQ Data

- WQ Simulation

- Compute Transport
  (Solver)

- Compute Temperature
  and Chemistry
  (WQ Modules)

- Output WQ Results

- Visualize Results
**Problem:** Currently, water quality modeling is performed separately from reservoir operation decision-making, with results being laboriously transferred between models, which have to be repeatedly adjusted and recomputed 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 to 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 as well as providing 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 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 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
Watershed Runoff Water Quality Modeling
HEC-HMS Water Quality Objective

• Build water quality modeling and analysis capabilities for HEC-HMS, in collaboration with ERDC Environmental Laboratory (ERDC-EL).
  • Implement simulation of the water temperature and user-defined general constituents for:
    • Overland flow
    • Streams
    • Reservoirs
• This will form the foundation for a generalized next-generation watershed water quality modeling system capable of simulating non-point source water quality (nutrients, dissolved oxygen, phytoplankton, and bacteria) and characterizing its effects on the watershed.
Watershed-Scale Water Quality Modeling
CWMS and HEC-WAT
Corps Water Management System (CWMS)

- CWMS (Corps Water Management System) provides real-time decision support for water management.
- 700+ Multi-purpose reservoirs, flow control structures, levees, etc.
- Features:
  - Real-time data acquisition
  - Database storage
  - Flow forecasting of watershed runoff
  - Reservoir operation decision support
  - River profile modeling
  - Inundated area determination
  - Consequence/damage analysis
  - Information dissemination
- Implementation Goal: 201 CWMS systems by 2022

- WQ development in HEC-ResSim, HEC-RAS, and HEC-HMS will provide real-time WQ capabilities in CWMS.
HEC-WAT (Watershed Analysis Tool)

Environmental

Hydraulics

Consequences

Hydrology

Reservoir
CE-QUAL-W2 Plug-In for HEC-WAT
Columbia-Snake-Clearwater Watershed
Total Dissolved Gas
Columbia-Snake-Clearwater Watershed
Total Dissolved Gas

- **Source:**
  - High flows plunging to great depths

- **Problem:**
  - Gas bubble trauma in fish
    - Increased predation
    - Injury
    - Infection
CE-QUAL-W2 2D Hydrodynamic & WQ Model

Water body segments

- Dissolved Oxygen
- Inorganic Carbon
- Dissolved Oxygen
- Diagenesis of Organic Matter
- Mass Transfer of CH4, H2S, NH4, NO3, DIP, DIC

Layer 1
- Production of CH4, H2S, NH4, DIP, CO2
- Reactions of CH4, H2S, NH4, NO3, DIP, DIC
- Burial

Layer 2
- Diagenesis of Organic Matter
- Production of CH4, H2S, NH4, DIP, CO2
- Reactions of CH4, H2S, NH4, NO3, DIP, DIC
- Burial

Water Column
- Algae
- Organic Matter
- DO

Sediment segments

- LDOC, LDON, LDOM
- RDOC, RDON, RDOM
- LPOC, LPON, LPOP
- RPOC, RPON, RPOP
- Benthic Sediment

- Inorganic Carbon
- Phosphate
- Ammonium

- Σ Agale
- Σ Epiphyton
- Σ Macrophyte
- Σ Zooplankton

- Water Column
- Dissolved Oxygen
- Inorganic Carbon
- Dissolved Oxygen
- Diagenesis of Organic Matter
- Mass Transfer of CH4, H2S, NH4, NO3, DIP, DIC

- Tailwater Channel
- Stilling Basin
- Spillway
- Forebay
Columbia-Snake-Clearwater Watershed
Total Dissolved Gas
Water Quality Web Pages

A set of water quality web pages was created that provide an overview of the ERDC-HEC collaboration and the water quality software being developed under this work unit, other EMRRP work units, and with District funding and collaboration.

The web pages include summaries of the ERDC-EL NSM and RVSM modules, the water quality capabilities being developed in HEC-RAS, HEC-ResSim, and HEC-HMS, technical references, sponsors, collaborators, and instructions for users to submit suggestions for improvements.

https://www.hec.usace.army.mil/software/waterquality/
Operational Strategies to Control Harmful Algal Blooms in Inland Reservoirs

Purpose:
• Provide guidance on operational management techniques and procedures (i.e. withholding or release of water, the use of targeted flow strategies like horizontal flushing or hypolimnetic withdrawals, etc.)

Results:
• A systematic historical study of the influence of reservoir control options on HABs.
• The development of modeling tools and protocols to allow reservoir managers to test the projected effects of operational changes.

Benefits:
• With increasing frequency of geographic distribution of HABs there is a need to understand what effects, if any, previous attempts to operationally manage HABs have been successful in reducing bloom extent, duration, and expression of toxins.

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USACE WQ Modeling: Watershed Systems Approach

HEC-RAS (1D/2D WQ)
- Fully integrated riverine hydraulic, sediment, and water quality model to aid users in determining Total Maximum Daily Loads (TMDLs).
- Can be linked to SWAT and HSPF

HEC-ResSim (1D WQ)
- Simulates reservoir operations at one or more reservoirs to meet multiple objectives for flood control, hydropower, water supply, navigation, recreation, and environmental management.
- For both planning studies and for real-time decision support.
- HEC-ResSim v4.0 has fully integrated water quality (WQ) modeling capabilities for environmental impacts analysis and operational support.
USACE Water Quality Modeling Tools

- Several models available with varying degrees of coupling between the hydrodynamic, nutrient, organism, and transport algorithms.
- Application domains range from run of river reservoirs to coastal zones.

**Example of interdependent nutrient cycles and algae growth**

**CE-QUAL-ICM**
- Fully 3D, time-variable; link to independent hydrodynamics
- 36 constituents
- Trophic interactions include submerged aquatic vegetation, multiple algae groups, sediment diagenesis, benthos, and zooplankton

**CE-QUAL-W2**
- 2D, laterally-averaged hydrodynamic and water quality model, 28 constituents
- Simulates stratified flow through variable density as affected by temperature, salinity, TDS, and TSS
- Can be extended to model entire basins
- Over 1600 known applications in 34 countries

**AdH-NSM-2D/3D**
- First model to fully couple hydrodynamics and water quality on an adaptive mesh
- Includes floating and benthic algae, interrelated N, P, C, and O₂ cycles

**Fully 3D, time-variable; link to independent hydrodynamics**

**3D constituents**

**Trophic interactions** include submerged aquatic vegetation, multiple algae groups, sediment diagenesis, benthos, and zooplankton
Science-Based Decision Making for Operational Management

- What can we do with models?
  - Simulate the effects of system changes due to environmental disturbances
  - Improve the effectiveness of sampling and management programs

- What areas need improvement in our models?
  - Automated data processing
  - GIS interactivity
  - Real-time calibration/validation
  - Web functionality
Team Members and Collaborators (Alphabetical)

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Thank You

Questions?