USACE Plug-In Water Quality Modules Developed for a Variety of Hydrologic and Hydraulic (H&H) Models

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Outline

- Background
- Water quality modules – dynamic linked libraries
- Water quality capabilities in a variety of H&H models
- Riparian vegetation simulation module
System Wide Water Resources Program

- GSSHA
- HEC-HMS
- HEC-RAS
- HEC-ResSim/CE-QUAL-W2
- AdH
Ecosystem Management and Restoration Research Program

- EMRRP products focus on cost-effective, science-based impact assessment, restoration, and management technologies for the Corps' water resource managers.
- EMRRP is targeted toward ecosystems of particular concern to the Corps, namely: streams, riparian and other floodplain, wetlands, and aquatic systems.
CWMS provides real-time decision support for water management

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: 201 CWMS systems by 2022
Real-Time Fully Integrated H&H Models in CWMS

HEC-HMS Runoff WQ

HEC-ResSim Reservoir WQ

HEC-RAS River WQ

WQMs (DLLs)

Courtesy of Todd Staissberg
H&H Models

- Completely mixed (0-order)
- One dimensional (1-D)
  - Longitudinal/Vertical
- Two dimensional (2-D)
  - Longitudinal and vertical
  - Depth averaged
- Three dimensional (3-D)

More data

River-run impoundment, longitudinally & vertically segmented

Elongated, shallow, longitudinally segmented
A Water Quality Model

3-D Transport Equation

\[
\frac{\partial C}{\partial t} = -\frac{\partial U_x C}{\partial x} + \frac{\partial}{\partial x} \left( E_x \frac{\partial C}{\partial x} \right) - \frac{\partial U_y C}{\partial y} + \frac{\partial}{\partial y} \left( E_y \frac{\partial C}{\partial y} \right) - \frac{\partial U_z C}{\partial z} + \frac{\partial}{\partial z} \left( E_z \frac{\partial C}{\partial z} \right) \pm \text{Sources and Sinks}
\]

Transport  
Physical process

Kinetics  
Biogeochemistry

Water Quality Model
Plug-In Water Quality Modules

Water Quality Modules (DLLs)
- Water temperature
- General constituents
- Nutrients (C,N,P)
- Contaminants
- Mercury

HEC-RAS (1D/2D)

HEC-ResSim

CE-QUAL-W2

SRH-2D

AdH (2D/3D)

• Kinetic rate
• Pathways
• Derived constituents

HEC-HMS

SWAT
Plug-in Water Quality Modules

- Modules
  - Water Temperature Simulation Module (TEMP)
  - General Constituent Simulation Module (GC)
  - Solid Simulation Module (SED)
  - Nutrient Simulation Module I (NSMI + SedFlux)
  - Nutrient Simulation Module II (NSMII + SedFlux)
  - Contaminant Simulation Module (CSM)
  - Mercury Simulation Module (HgSM)

- References
  - Aquatic Nutrient Simulation Modules (NSMs) developed for hydrologic and hydraulic models [link]
  - Application and Evaluation of the HEC-RAS-Nutrient Simulation Module (NSMI) [link]
  - Aquatic Contaminant and Mercury Simulation Modules developed for hydrologic and hydraulic models [link]
  - Verification and Evaluation of Aquatic Contaminant Simulation Module (CSM) [link]
Water Quality Modules (DLLs) – Kinetics (Biogeochemical Reactions)

Water column

Bed sediment

Active sediment layer

Multi sediment layers

Area
Nutrient Simulation Modules

**EUTROPHICATION**
Excessive plant growth

- **PHYTOPLANKTON**
  Floating microscopic algae

- **PERIPHYTON & FILAMENTOUS ALGAE**
  Attached algae

- **MACROPHYTES**
  Higher vascular rooted plants

Predominently in shallow systems (streams or nearshore regions of lakes & estuaries)
Contaminant Simulation Module

- Soluble
- Complexes with organic ligands
- Algae
- Detritus
- Inorganic Solids (silt, clay, sand)

Water column

DOC
Sorbed Phase

Dissolved Phase

Sorbed Phases
Algae
POM
Solids

Degradation
Hydrolysis
Photolysis
Transformations

Volatilization

Bed sediment

DOC
Sorbed Phase

Dissolved Phase

Sorbed Phases
POM
Solids

Burial

Resuspension

Equilibrium

Non-equilibrium

Diffusion

Degradation Transformations

Equilibrium

Non-equilibrium
**Elementary Hg (Hg0)**
**Inorganic Hg (HgII)**
**Organic Hg (MeHg)**

**Water column**
- Volatilization
- Photodegradation
- Oxidation
- Reduction
- Diffusion
- Deposition
- Resuspension

**Bed sediment**
- Burial
- Demethylation

**Hg Simulation Module**
HEC-ResSim (Reservoir System Simulation) Water Quality

Water quality should influence flows

- HEC-ResSim
  - Evaluate Flow and WQ at every time step
- WQ Rules
- WQ Libraries
- Decision Engine
- WQ Engine

Releases

Courtesy of Todd Staissberg
HEC-ResSim Water Quality

1D River

1D Reservoir

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density

temperature

THERMOCLINE
HEC-RAS (River Analysis System)  
Water Quality

Water Quality Data  
Analysis
Lower Minnesota River TMDL

Twelve (12) tributaries
Eight (8) point sources

(Courtesy of MCES)
Lower Minnesota River HEC-RAS Water Quality Model
Comparison of Modeled Results and Observed Data at RM 3.5

- **Organic phosphorus**
- **Dissolved inorganic phosphorus**
- **Algal concentration**
- **Dissolved oxygen**
Comparison of Modeled Results and Observed Data at RM 3.5

Algae vs. Dissolved oxygen

Organic nitrogen

Nitrate-Nitrite nitrogen

Ammonium nitrogen
Linked HSPF and HEC-RAS model for the Calleguas Creek Watershed

Map Location

NH4 (mg/L)

Observed
Simulated

TP (mg/L)

Observed
Simulated

TSS (mg/L)

Observed
Simulated

Ammonium Nitrogen

Total Phosphorus
Linked HSPF and HEC-RAS model for the Patuxent Watershed

Algal Concentration
Patuxent River near Bowie, MD

Dissolved Oxygen Concentration
Patuxent River near Bowie, MD
Missouri River Recovery Management Plan
Columbia River System Operations (CRSO)

- CRSO
  - 12 Corps dams
  - 2 BOR dams
  - BPA markets the power generated from the dams
- Evaluate impact of operation and configuration of federal dams on:
  - Water temperature
  - Total dissolved gases (TDG)

Courtesy of Dan Turner
Enhancement of CE-QUAL-W2

- SYSTDG
- SedFlux, Carbon Cycle, HgSM

River Section: Slope $= S = \tan \alpha$

Reservoir Section

$Q_{\text{out}}$
CRSO Water Quality Models

CE-QUAL W2, 2-D modeling
HEC-RAS, 1-D modeling
model connections
Federal dam
Non-Federal dam
Boundary condition gage

Canadian System
Albeni Falls
Libby
Hungry Horse

Columbia River International Bndy
Grand Coulee
Chief Joseph
Rocky Reach
Rock Island
Wanapum
Priest Rapids
Hanford Reach

Dworshak
Clearwater River Orofino

Lower Granite
Little Goose
Snake River Anatone

Lower Mon.
Hanford Reach

Ice Harbor
McNary

Columbia River
McNary
John Day
The Dalles
Bonneville
Washougal

 Courtesy of Dan Turner
SRH-2D (Sedimentation and River Hydraulics) Water Quality

- TEMP, GC modules
- NSMI, HgSM modules
AdH (Adaptive Hydraulics) Water Quality

- TEMP, GC modules
- NSMI, CSM modules

Three testing modes:

- No flow “bathtub”
- Simple flume
- Field case

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**Graphs**

- **ORGN**
  - Increased denitrification

- **NO3**
  - Increased Denitrification
  - Original

- **NH4**
  - increased Denitrification
  - Original
RVSM (Riparian Vegetation Simulation Module)
Developed for 1D and 2D Hydraulic Models
Processes of vegetation life cycle

- Seedling establishment
  - Germination period
  - Seed dispersal
- Plant growth
  - Growth rate (stalk, root)
  - Max height/depth for stalk/root
  - Effects on roughness through growth
- Mortality
  - Competition
  - Scour (high flows on young plant)
  - Drowning (inundated for duration)
  - Desiccation (root growth < GW drop)
  - Ice, burying

Plant height, root depth, canopy width, stem diameter etc. are computed
RVSM --> 1D/2D Hydraulic Models

- **HEC-RAS** – 1D/2D
- **SRH** - 1D/2D
Application of HEC-RAS-1D-RVSM to Sacramento River

- Study area
  - from Red Bluff to Colusa with 107 miles
  - Ecological management zone
  - Abundant vegetation data
  - Restoration projects were implemented

- Purposes
  - Model interactions between flow and vegetation
  - Predict vegetation area change
  - Examine what caused vegetation establishment change
### Application of HEC-RAS-1D-RVSM to Sacramento River

#### Table:

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<th>Year</th>
<th>Cottonwood</th>
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<th>Riparian shrub</th>
<th>Invasive species</th>
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#### Diagrams:

- **RM183**
  - Measured seedling density
  - Simulated Seedling area

- **RM192.5**
  - Measured seedling density
  - Simulated Seedling area
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