Integrating Water Resources Infrastructure with Upland Management to Advance Nature-Based Solutions for Water Quantity and Quality

Todd E. Steissberg, PhD, PE
Ecohydrology Team
Environmental Laboratory
Engineer Research and Development Center (ERDC)
U.S. Army Corps of Engineers (USACE)

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ENGINEER RESEARCH & DEVELOPMENT CENTER

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Engineering With Nature (EWN) Research and Development Team

U.S. Army Corps of Engineers

- Todd Steissberg
- Lauren Melendez
- Lora Johnson
- Mitch Delcau (ERDC/LimnoTech)
- Isaac Mudge
- Kelsey Walak
- Rose Shillito
- Jodi Ryder
- Joanna Curran
- Mary Spiers
- Todd Swannack

Arizona State University

- Rebecca Muenich
- Selcuk Candan
- Ting Liu
- Amber Wutich

Texas A&M & USDA

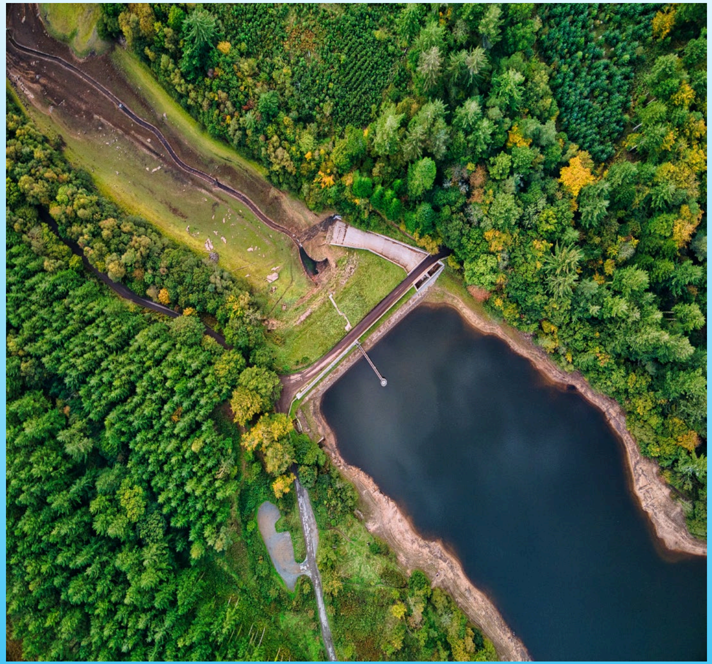
- Raghavan “Srini” Srinivasan
- Terry Nipp
- Allan Jones

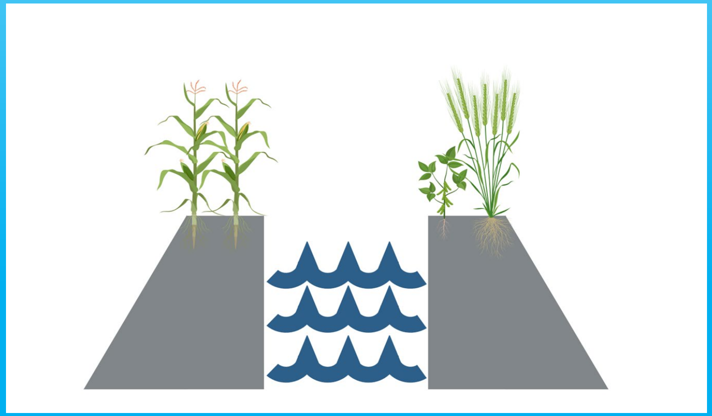
LimnoTech

- Billy Johnson
- Anthony Aufdenkampe
- Sarah Jordan
- Jason Rutyna
- Honna Steissberg
- Tad Slawecki

Introduction: Problems

- Maintaining water quality while managing water resources is a difficult goal to achieve, due to:
  - Extreme conditions: precipitation, flow, temperature, and runoff that carries heavy loads of nutrients and other contaminants
  - Multiple drivers and potential control points throughout the system
- Water quantity and quality is influenced at many points as it flows through the watershed:
  - Rain: Source areas in the uplands (precipitation, snow melt, agricultural sources, springs, etc.)
  - Runoff: Transport across the landscape (runoff and sub-surface flow)
  - Rivers: Flows into and through stream networks
  - Reservoirs: Flows into reservoirs or other water infrastructure
- Basins across the U.S. face extremes on both ends of the climate spectrum: flooding and drought
- Management of upland landscapes (e.g., agricultural lands) or land adjacent to reservoirs, levees, and other water infrastructure systems is often not aligned with the infrastructure management itself, particularly neglecting to ensure water quality alongside water quantity.

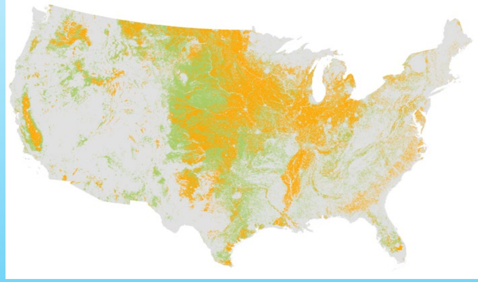




ASU-ERDC Engineering With Nature (EWN) Collaboration

- There are many land-use types across the basins that USACE and other government agencies manage
- Agricultural lands represent the majority of non-government owned land in the U.S.
    - These lands are often co-located with water resources infrastructure and are actively managed, often with practices similar to NNBF.
    - Coordination and eventual integration of USACE activities (particularly EWN) with upland agricultural management will help reduce system-wide inefficiencies and produce more synergistic outcomes for water quantity and quality.
- Examples of these coordination activities include:
    - Reservoir management with upland agricultural land management
    - Coordinating NNBF solutions (e.g., levee plantings and setbacks) with existing agricultural land management and conservation practice implementation.

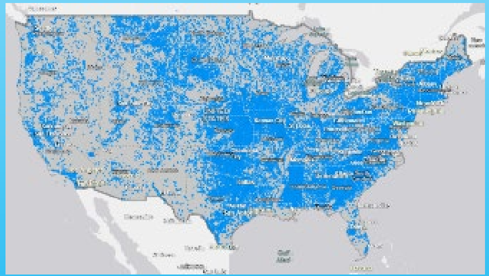
Agricultural lands and water resources infrastructure in the Continental U.S.



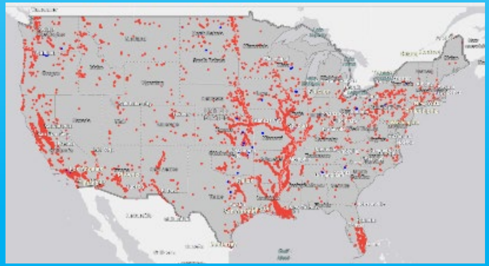
Agricultural lands from USDA

green = pasture/range

orange = cropland



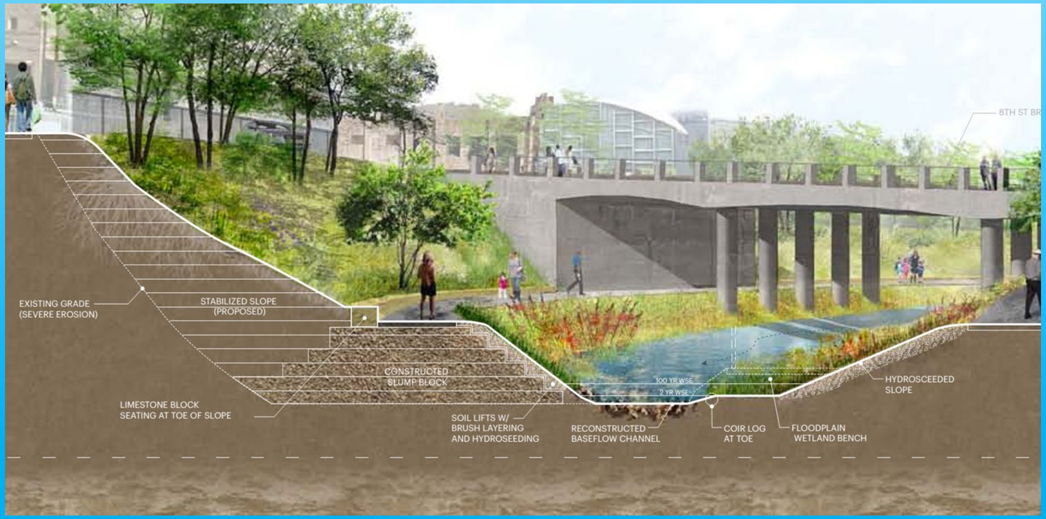
Reservoir locations from USACE



Levee locations from USACE

Engineering With Nature (EWN)

Engineering with Nature (EWN) is an approach in engineering and design that seeks to work in harmony with the natural environment rather than against it. It involves incorporating ecological principles and processes into engineering projects to enhance sustainability, resilience, and the overall health of ecosystems. This approach aims to create infrastructure solutions that not only fulfill human needs but also promote biodiversity, ecosystem services, and the long-term well-being of both humans and the natural world.



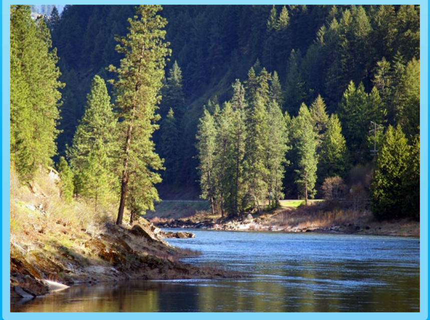
Courtesy of LimnoTech

EWN Solutions

To address the challenges related to maintaining water quality while managing water resources, EWN and integrated hydrology and water quality models should be utilized. Potential solutions include:

- Nature-Based Solutions: Implementing green infrastructure such as constructed wetlands, biofiltration systems, and vegetative buffer strips can help intercept and treat runoff, reducing the transport of contaminants into water bodies. These nature-based solutions can enhance water quality while providing additional benefits such as flood mitigation and habitat creation. These solutions can often leverage existing Best Management Practices (BMP) that have already been implemented in upland landscapes and agricultural lands to help reduce nutrient and sediment runoff. Examples of BMPs include precision agriculture techniques, cover cropping, conservation tillage, and nutrient management plans. These practices can minimize the impacts of extreme conditions on water quality.

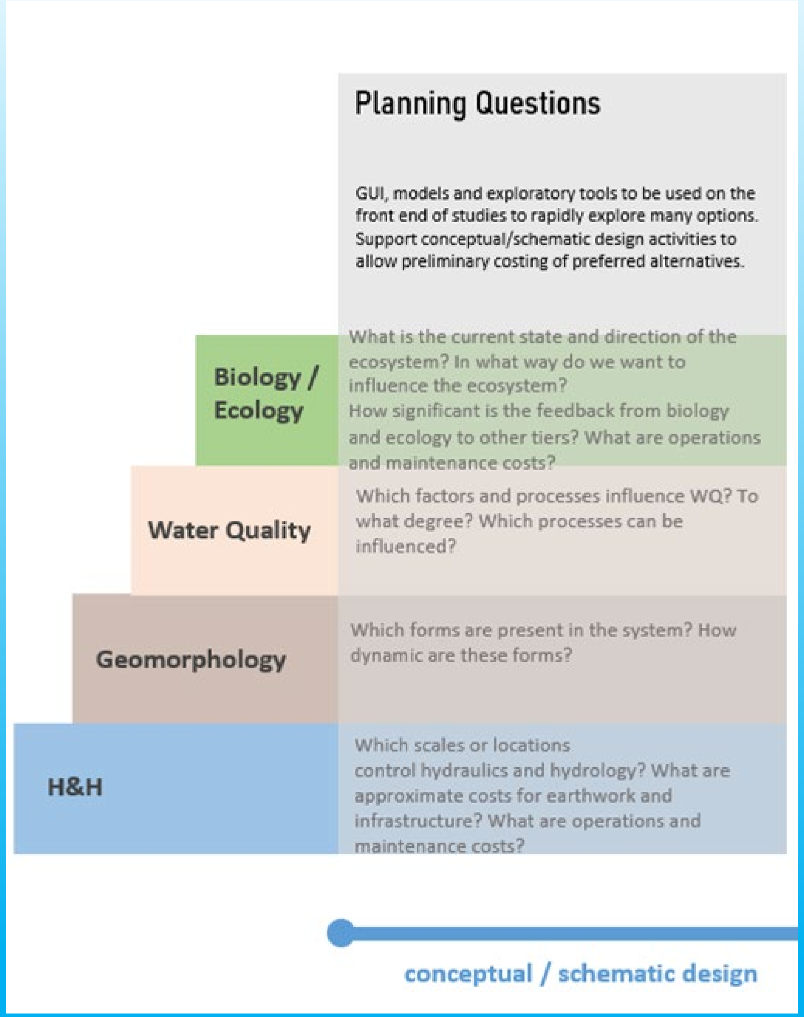
- Watershed-scale Management: Adopting a holistic approach to water resource management by considering the entire watershed can help identify and address multiple drivers and control points. This involves coordinated efforts among stakeholders, including landowners, farmers, industries, and water management agencies, to implement strategies that improve both water quantity and quality throughout the system.



- Integrated Hydrology and Water Quality Models: Developing and utilizing integrated hydrology and water quality models can provide valuable insights into the complex interactions between water quantity and quality. These models can simulate the movement of water, nutrients, and contaminants through the watershed, allowing for scenario analysis and the evaluation of different management strategies.

Integrated Hydrology and Water Quality Models and Methods

- By implementing these solutions, it is possible to achieve the dual goals of maintaining water quality while managing water resources effectively, even under extreme conditions and across different points within the hydrological system.
- How do we quantify and realize landscape-scale benefits to water quantity and quality in integrated and complex systems?
  - We need a modeling framework that can take complex site-specific interactions and upscale these disparate interactions on a system-wide and aggregated scale.



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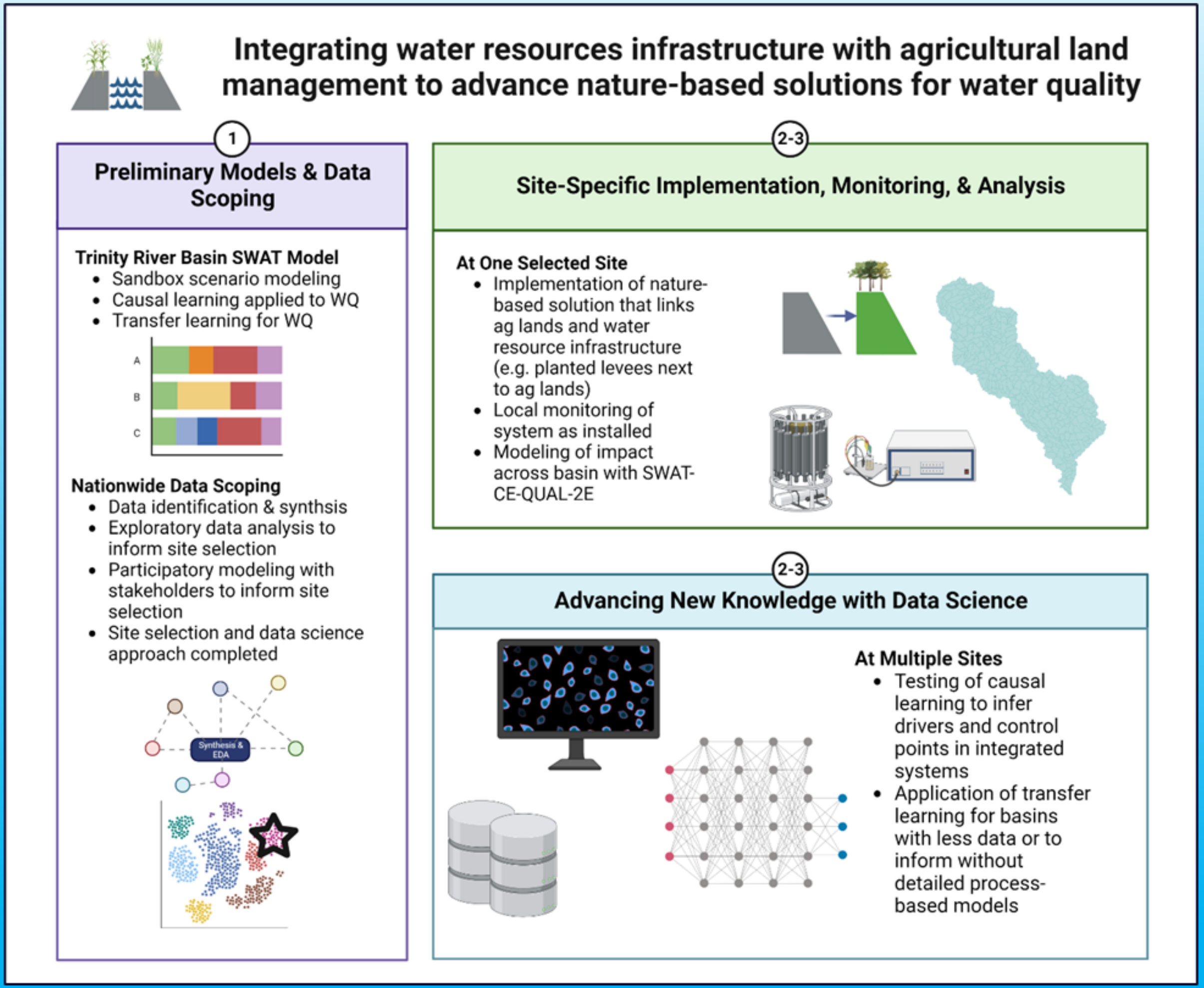
Engineering With Nature (EWN) Collaboration

- Our primary objectives in the first three years are to
  - Assess the feasibility of this approach through nationwide data scoping and stakeholder engagement
  - Develop the modeling and data science tools and methods to inform best practices and enable USACE to locate and evaluate opportunities for NNBF across USACE-managed systems.
- This project will
  - Address large knowledge gaps regarding how these systems work
  - Identify new strategies to advance where, when, and how these integrated landscapes can be better managed to mimic larger-scale, natural processes for a system-wide EWN approach that utilizes new and state-of-the art modeling and data science techniques.

Engineering With Nature (EWN) Collaboration

Objectives:

1. Identify the potential for integrated management of upland areas and traditional water resources infrastructure (e.g., reservoirs, levees) across the U.S.
2. Select and model at least one of these systems at the watershed-scale, based on data scoping and stakeholder preferences from objective 1.
3. Implement, test, and monitor the performance of at least one nature-based solution in the selected system.
4. Develop methods to transfer learning and emulation modeling techniques to simulate and understand processes driving and controlling water quantity and quality in these integrated systems.
5. Apply the models, methods, and data from objectives 1-4 to demonstrate the applicability of this integrated system management in basins across the U.S.

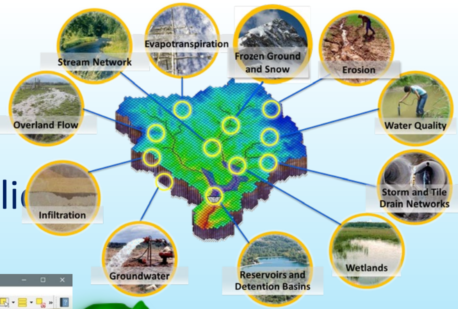


Environmental Modeling Capabilities

- Linking water quality (WQ) capabilities with existing hydrologic or hydraulic (H&H) models streamlines workflows and reduces costs. The U.S. Army Corps of Engineers (USACE), USDA, and other organizations have several widely deployed models that simulate watershed runoff, river hydraulics, and reservoir operations.
- Our team at USACE-ERDC has ClearWater (Corps Library for Environmental Analysis and Restoration of Watersheds). ClearWater provides environmental simulation capabilities that are designed to leverage existing hydrologic and hydraulic (H&H) models.
  - The ClearWater modules simulate constituent kinetics, heat budget processes, and vegetation growth cycles. These modules include:
    - 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
  - The ClearWater engine computes the transport (advection and diffusion) of heat and mass across the watershed
  - ClearWater supports a wide range of data visualization and reporting capabilities
  - ClearWater provides a framework to integrate multiple models.

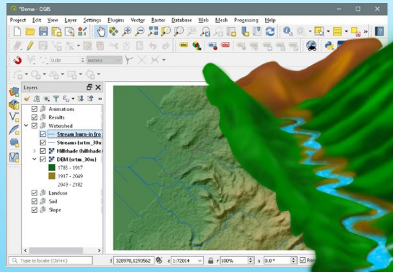
Clearwater River Watershed

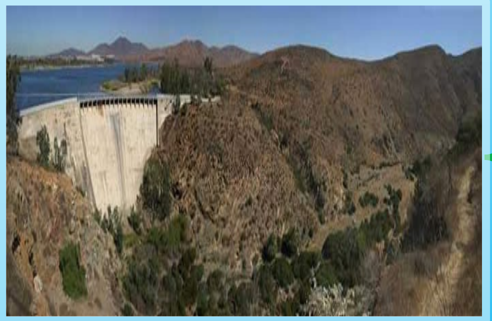
Water Quality and Environmental Systems Modeling

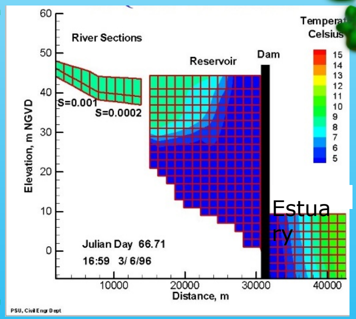


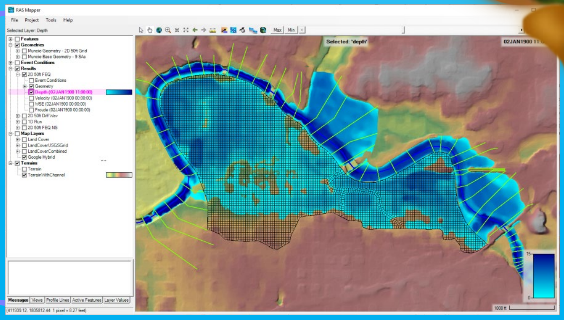
- Temperature
- Nutrients
- Dissolved Oxygen
- Algae
- Metals
- Contaminants
- Riparian Vegetation

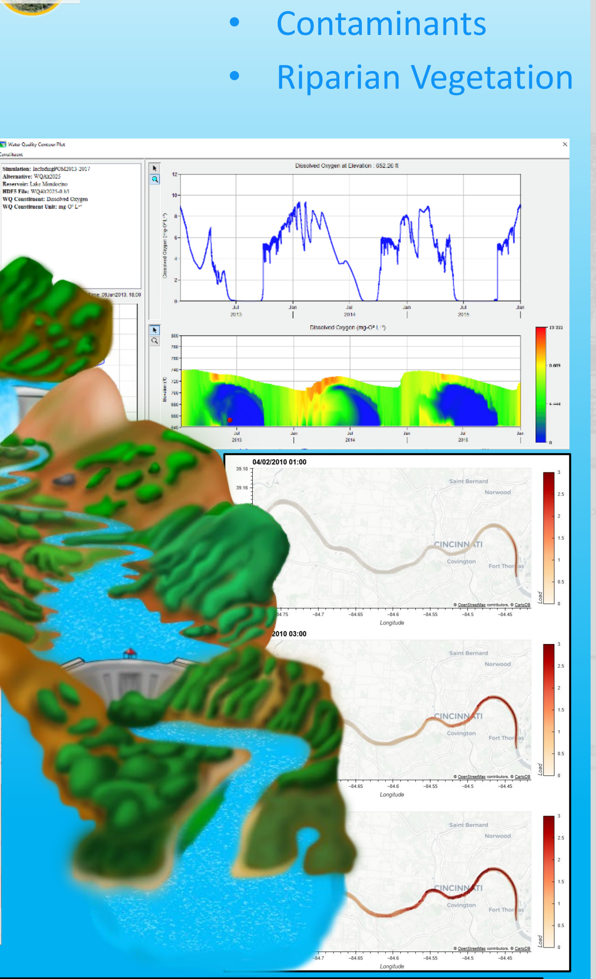
- The Corps Library for Environmental Analysis and Restoration of Watersheds (ClearWater) provides environmental simulation capabilities that leverage existing hydrologic and hydraulic (H&H) models.
- Watershed Runoff:
  - **SWAT:** Watershed water quantity and quality modeling
  - **GSSHA**: Surface and sub-surface water quality modeling and Nature-Based Features design tool
- Reservoirs:
  - **CE-QUAL-W2**: 2D reservoir-river hydrodynamics and water quality modeling
  - **HEC-ResSim**: Reservoir operations and water quality modeling
- Rivers and Floodplains:
  - **HEC-RAS**: 1D River hydraulics and water quality & vegetation modeling
  - **ClearWater-Riverine**: 2D River-floodplain hydraulics and water quality modeling with HEC-RAS and GSSHA





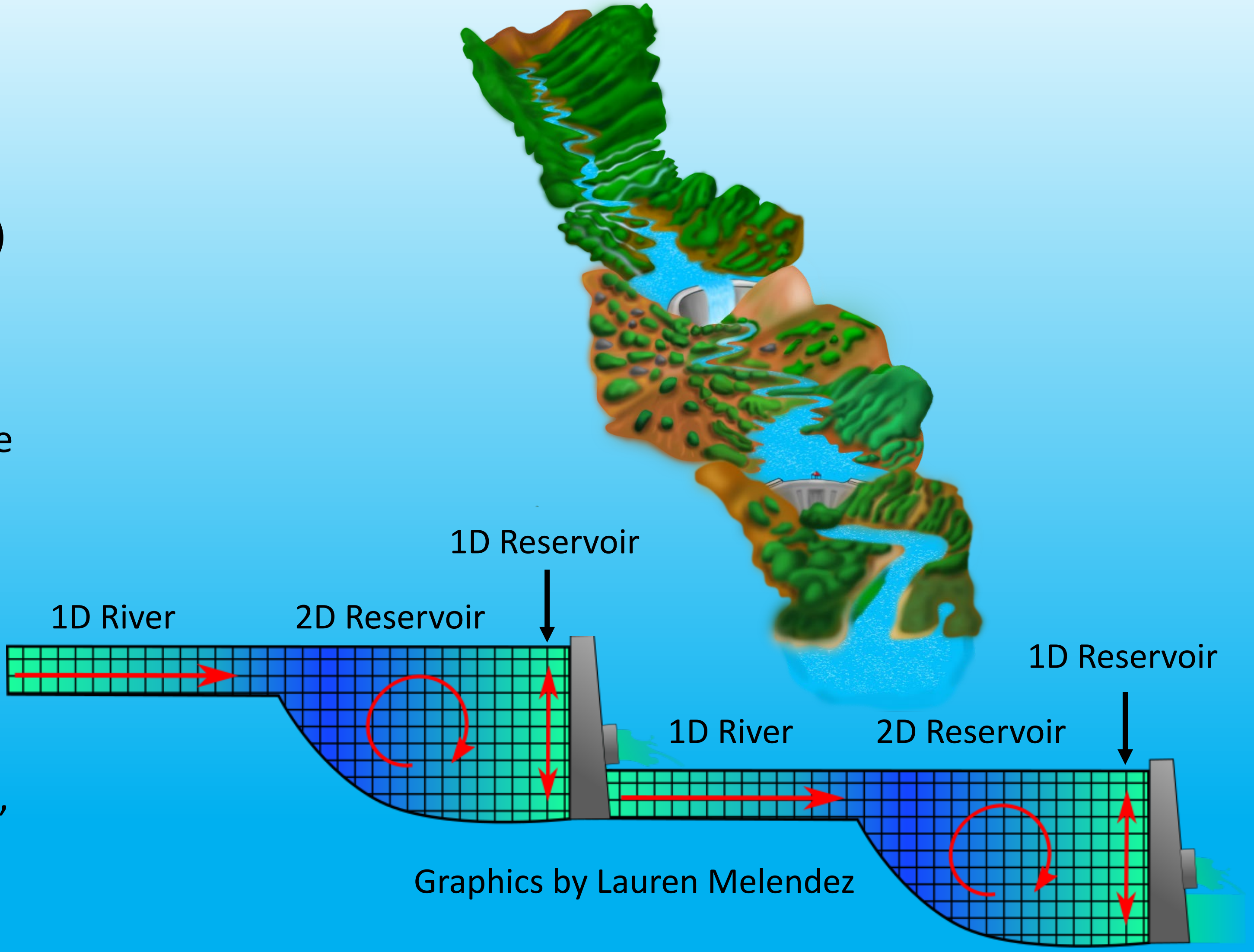






Model Dimensions, River-Reservoir System

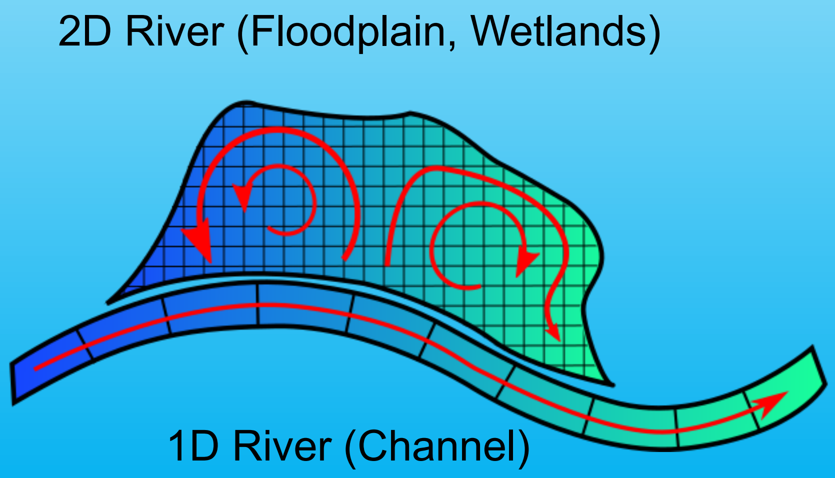
- Unstratified river/reservoir reaches:
  - May be modeled as 1D water bodies (segments)
- Stratified reaches:
  - May be modeled as 1D reservoirs (layers) for real-time release decision-making to meet downstream objectives
  - To characterize and understand in-reservoir processes, reservoirs need to be modeled as 2D water bodies (layers and segments)
    - Ensures accuracy, capturing important in-reservoir processes (mixing, pollutants, inflows, etc.)
    - Identifies vulnerabilities and restoration/management options (e.g., velocities and temperature for HAB management)

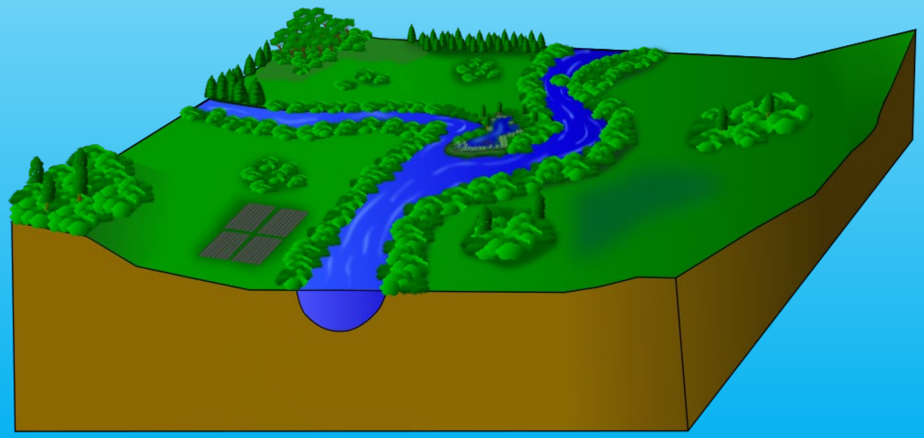


Graphics by Lauren Melendez

Model Dimensions: River-Floodplain System

- Unstratified river channels are often modeled as 1D water bodies, varying from upstream to downstream
- Hydrologic connectivity across the floodplain is important
- Floodplains need to be modeled as 2D water bodies, varying in all directions across the landscape

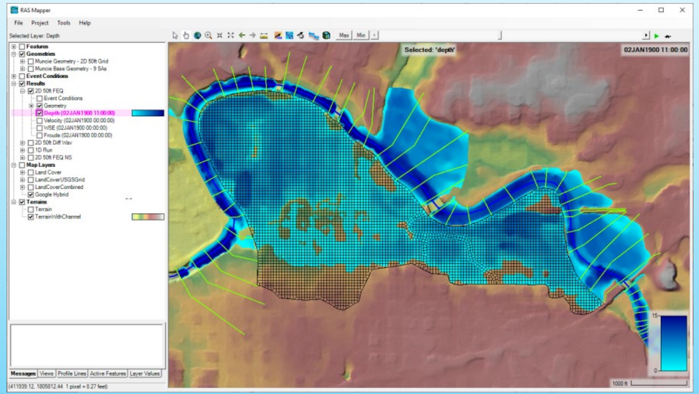


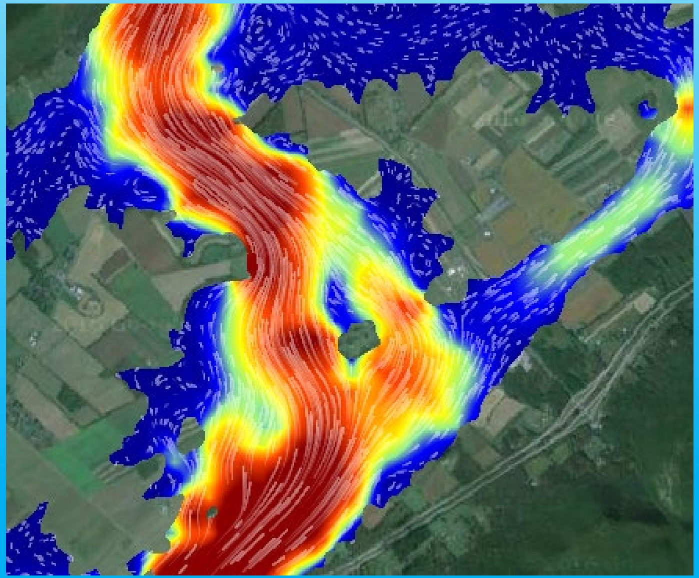


Graphics by Lauren Melendez

HEC-RAS-2D: Features and Benefits for Environmental Modeling

- HEC-RAS-2D is a powerful hydraulic modeling tool for environmental modeling.
- Features:
  - 2D hydraulic modeling captures spatial variability for complex river systems (e.g., braided channels) and provides accurate results
  - Enables floodplain mapping and analysis for flood risk assessment
  - Incorporates sediment transport modeling
  - Supports environmental analysis by providing water flows flows, velocities and depths for a wide variety of complex hydrologic events
- Benefits:
  - Improved accuracy and reliability
  - Comprehensive analysis and visualization capabilities
  - Efficient planning and design of hydraulic structures
- ClearWater-Riverine model can be linked with 2D HEC-RAS for additional capabilities:
  - 2D water quality modeling
  - Ecohydrology analyses
- 2D HEC-RAS, in conjunction with ClearWater-Riverine, offers a comprehensive solution for floodplain management, sediment transport analysis, and habitat assessment.



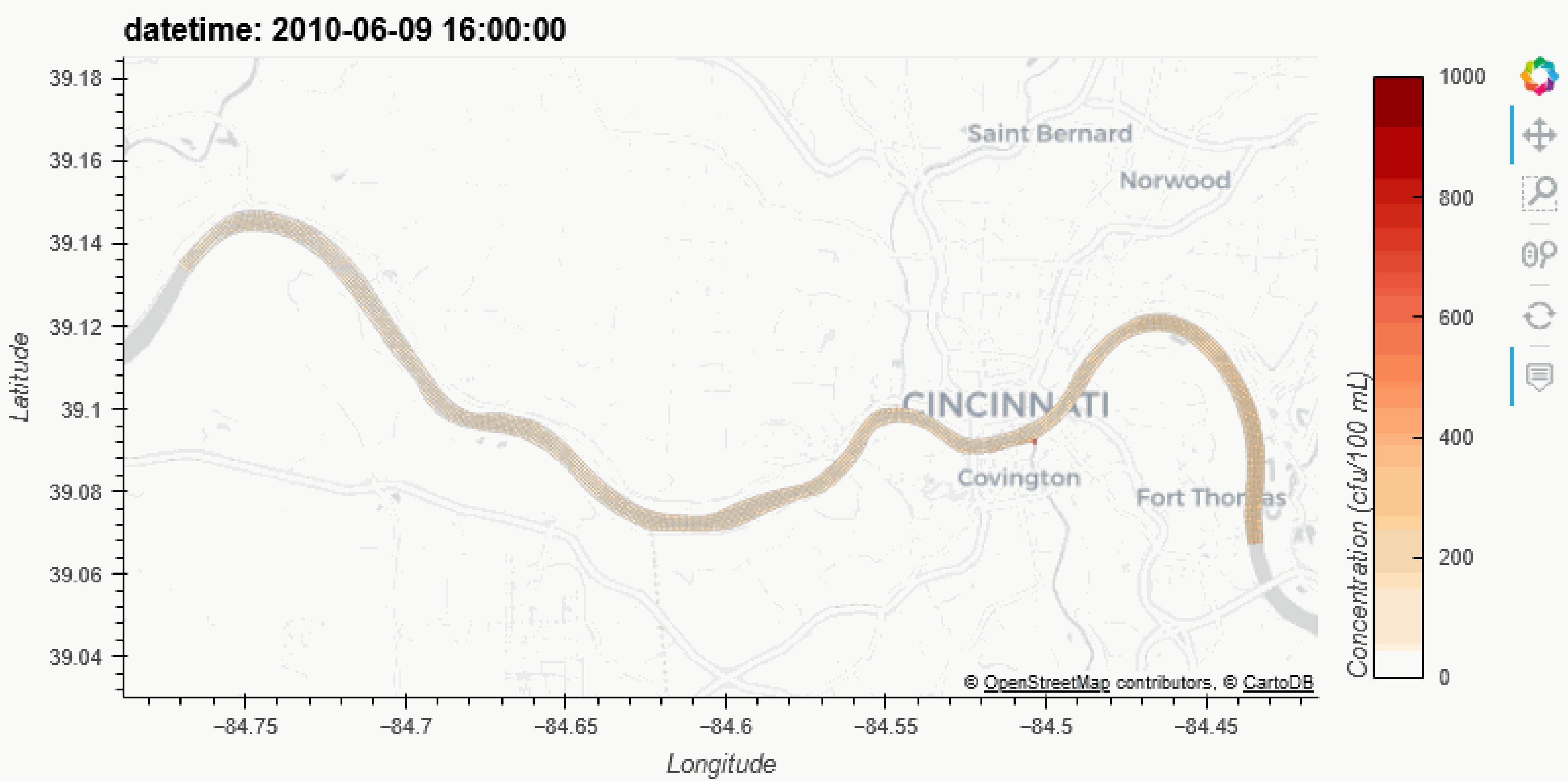


ClearWater-Riverine

- The Environmental Laboratory at USACE-ERDC is leading development of a state-of-the-art water quality model, Clearwater-Riverine, that simulates temperature and advanced nutrient cycling in branching river systems and floodplains, incorporating hydrodynamic, water quality, and meteorologic inputs from multiple data sources and models.
- ClearWater-Riverine will enable the evaluation of system vulnerabilities and identification of adaptation pathways to improve the resilience of floodplain ecosystems to environmental stresses, which include increasing frequency and intensity of extreme precipitation events and decreasing freshwater flows.
- Water quality kinetics, heat budget, and transport simulation capabilities in ClearWater-Riverine are furnished by ERDC's ClearWater modules.
- The ClearWater-Riverine framework links the capabilities provided by the ClearWater modules and advection-diffusion engine with the two-dimensional (2D) HEC-RAS model.
- HEC-RAS models have been developed for most of the watersheds around the world. By leveraging these existing models, ClearWater-Riverine provides a cost-effective, data-driven tool for impact assessment, planning studies, and the restoration and management of aquatic ecosystems.

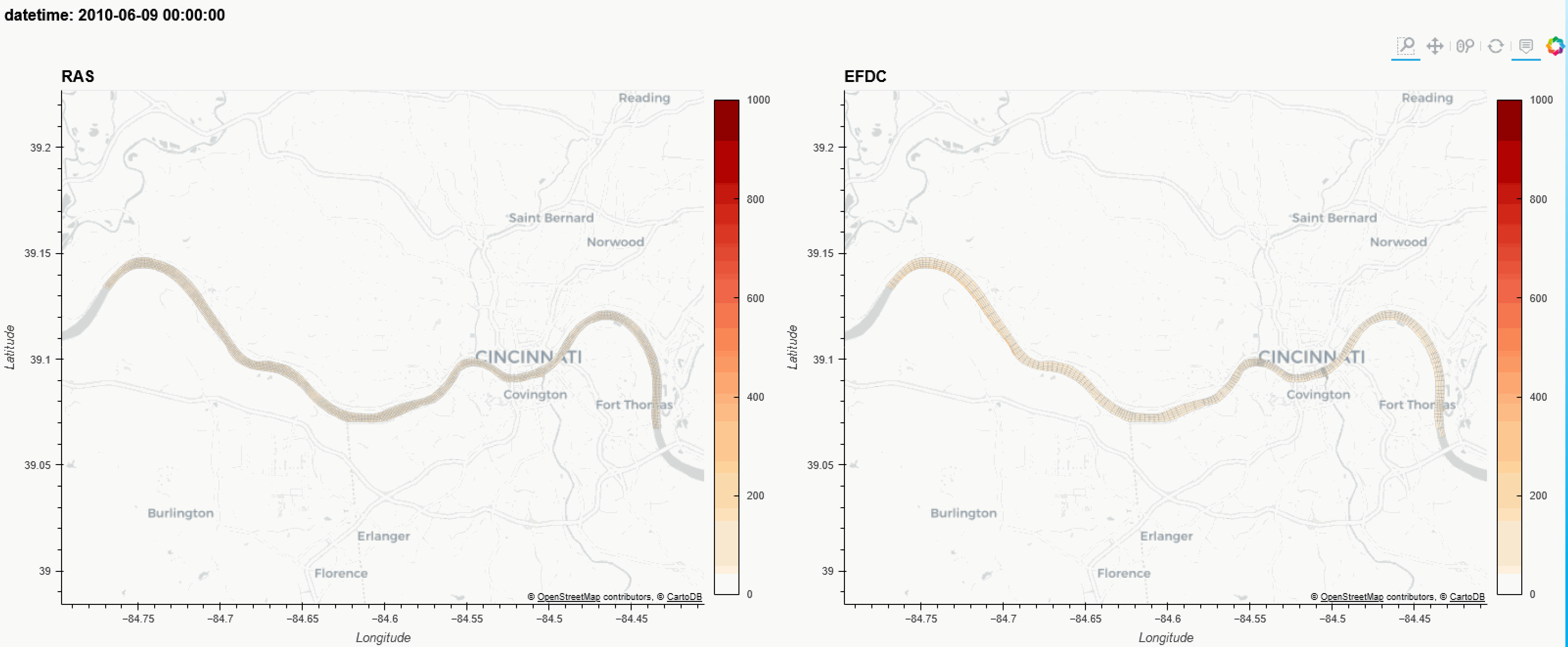
Source: https://unsplash.com/

ClearWater-Riverine: E. Coli Transport in the Ohio River



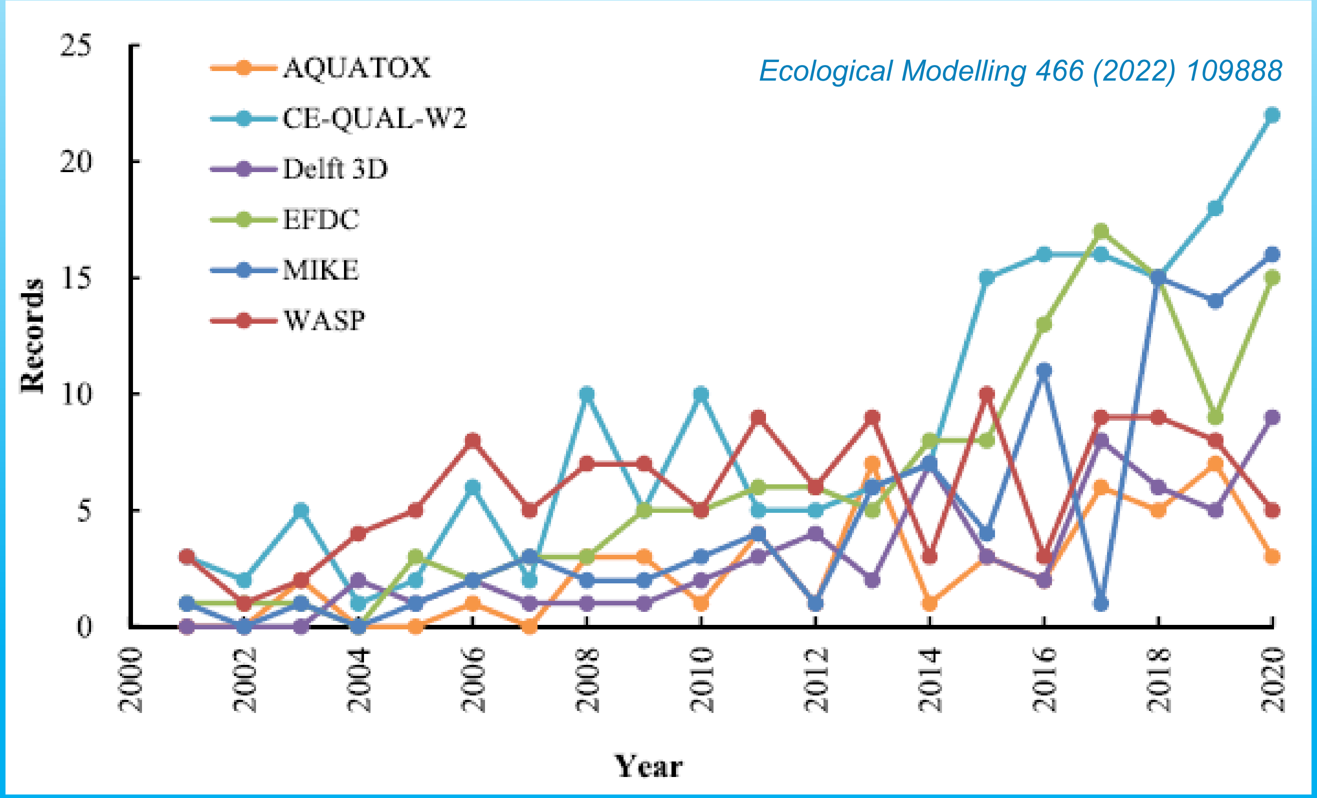
ClearWater-Riverine:

Comparison of ClearWater-Riverine (left) with the EFDC model (right)



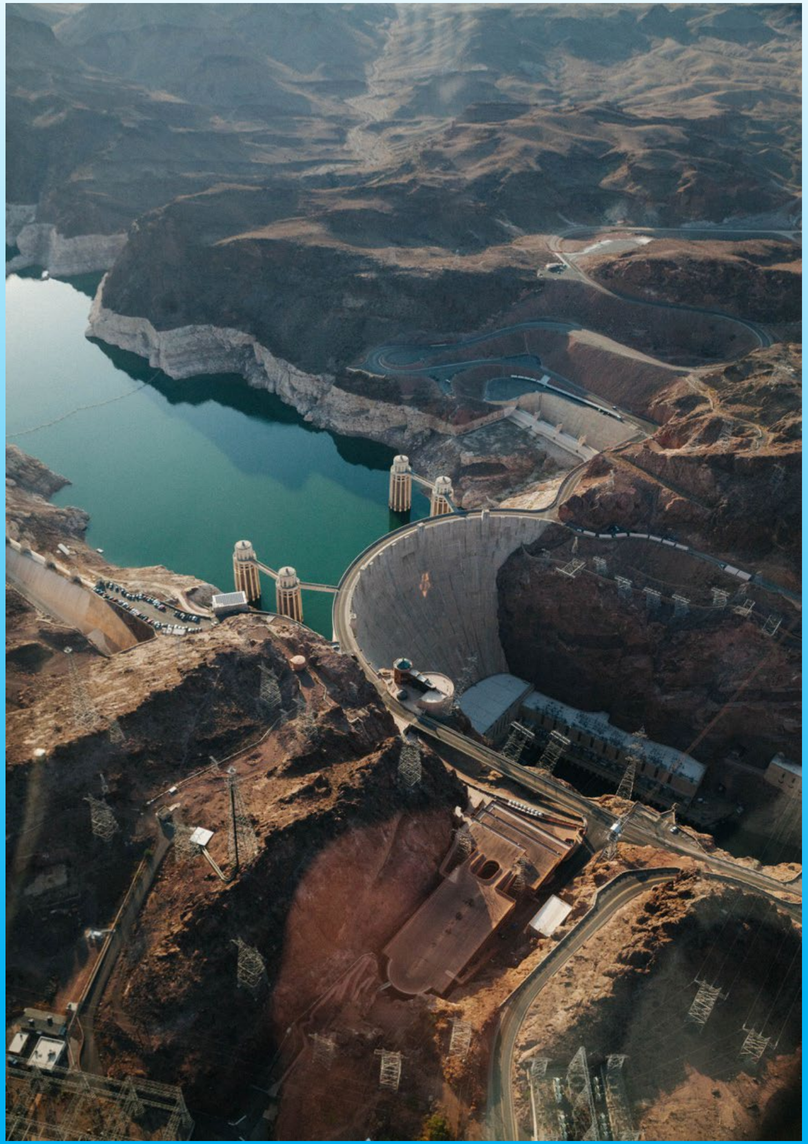
CE-QUAL-W2 Overview

- CE-QUAL-W2 is a two-dimensional (2D), longitudinal/vertical, hydrodynamics and water quality model that enables characterization of vertical and longitudinal changes in reservoirs.
- The model assumes reservoirs are *well mixed* laterally, with no variation from one channel side to the other in a layer (vertical) and segment (longitudinal).
- CE-QUAL-W2 is applied to rivers, lakes, reservoirs, estuaries, and combinations thereof.



CE-QUAL-W2 Model Benefits

- Since 1986, CE-QUAL-W2 has been used by water quality managers to assess impacts of management strategies on reservoir, lake, and estuarine systems.
- CE-QUAL-W2 computes the two-dimensional velocity field for narrow systems that stratify.
- In contrast with reservoir models with simplified hydrodynamics, CE-QUAL-W2 accurately simulates vertical and longitudinal transport of constituents, which can be as important as chemical kinetics in accurately simulating water quality.
- Applications of CE-QUAL-W2 include
    - Planning Studies
    - Environmental Impact Assessments
    - Ecosystem Restoration Projects
    - Real-Time Systems Operation and Decision-Making



Conclusions

- Key Points: This study presents a collaborative endeavor between USACE, Arizona State University, Texas A&M, USDA, and LimnoTech. The partnership focuses on integrating water resources infrastructure with upland management using a blend of hydrologic and water quality models: SWAT, CE-QUAL-W2, and ClearWater.
- Significant Challenges: The dynamic and complex nature of water systems, marked by extreme conditions and various control points, makes it difficult to maintain water quality while managing water resources effectively.
- Integrated Approach: An integrated approach that combines traditional infrastructure management, upland landscape management, and state-of-the-art modeling techniques offers promising avenues for improving water quality and quantity.
- The Role of EWN: Our Engineering with Nature (EWN) approach, guided by ecohydrology principles and process-based modeling, strives to bring harmony between human needs and environmental well-being.
- Nature-Based Solutions: Green infrastructure, best management practices, and nature-based solutions like constructed wetlands and vegetative buffer strips prove effective in mitigating the impacts of extreme conditions on water quality.

Conclusions

- Watershed-scale Management: We emphasize a holistic, watershed-scale management strategy that engages various stakeholders and uses integrated hydrology and water quality models to address multiple drivers and control points.
- Advanced Modeling Framework: The use of advanced modeling systems like ClearWater and CE-QUAL-W2, which leverage existing hydrologic and hydraulic (H&H) models, offers a way to quantify and realize landscape-scale benefits to water quantity and quality.
- Future Work: Our project aims to fill significant knowledge gaps and develop innovative strategies for managing integrated landscapes that mimic larger-scale, natural processes.
- Next Steps: Our objectives for the next three years include nationwide data scoping and stakeholder engagement, developing modeling and data science tools, and locating and evaluating opportunities for nature-based solutions across USACE-managed systems.
- Closing Remarks: Through this research, we hope to inspire a global shift towards sustainable and resilient water resources management, contributing to the overall health of our ecosystems and human well-being.

Questions?