Advancing Water Quality Modeling for Effective Prediction and Management of Harmful Algal Blooms

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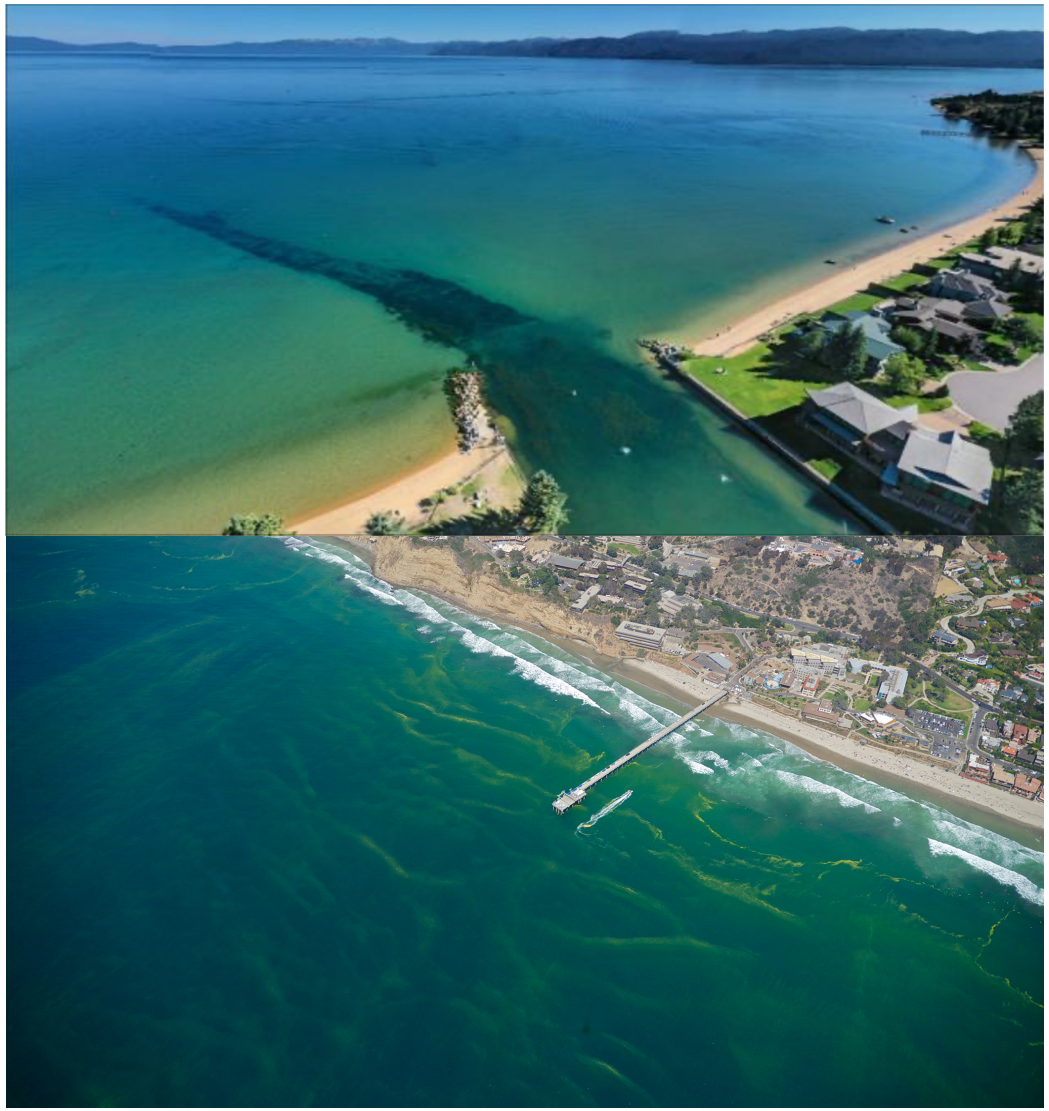
International Soil and Water Assessment Tool (SWAT) Conference

July 11, 2024

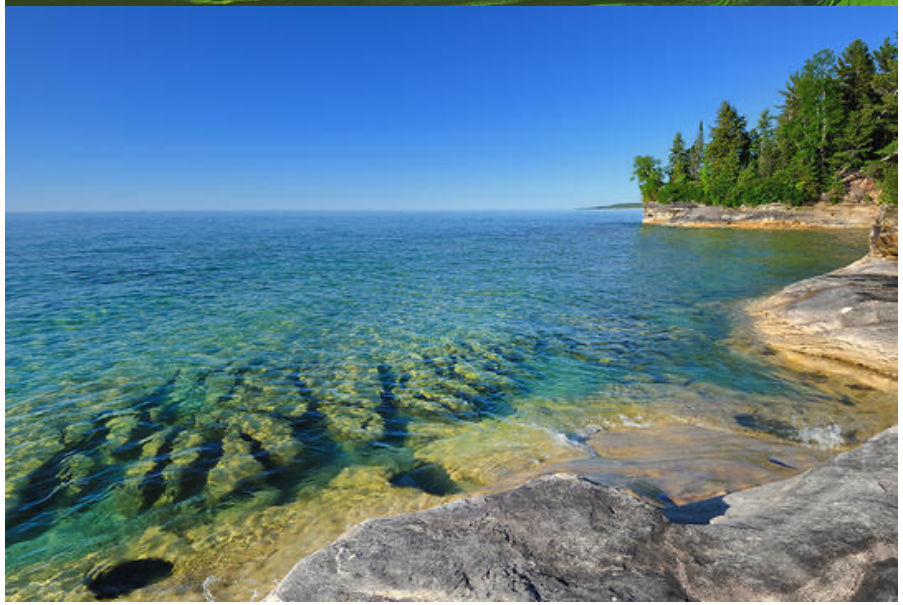
Introduction

- Harmful Algal Blooms (HABs) occur when colonies of algae grow out of control and produce toxic or harmful effects on people, fish, shellfish, mammals, and birds.
- Algae blooms can deplete dissolved oxygen in the water and/or release toxins that are harmful to human and ecosystem health through exposure to contaminated water or affected seafood.
- The algae in toxic blooms can produce neurotoxins which directly affect fish and other marine life leading to massive fish kills and the accumulation of toxins in the food chain.



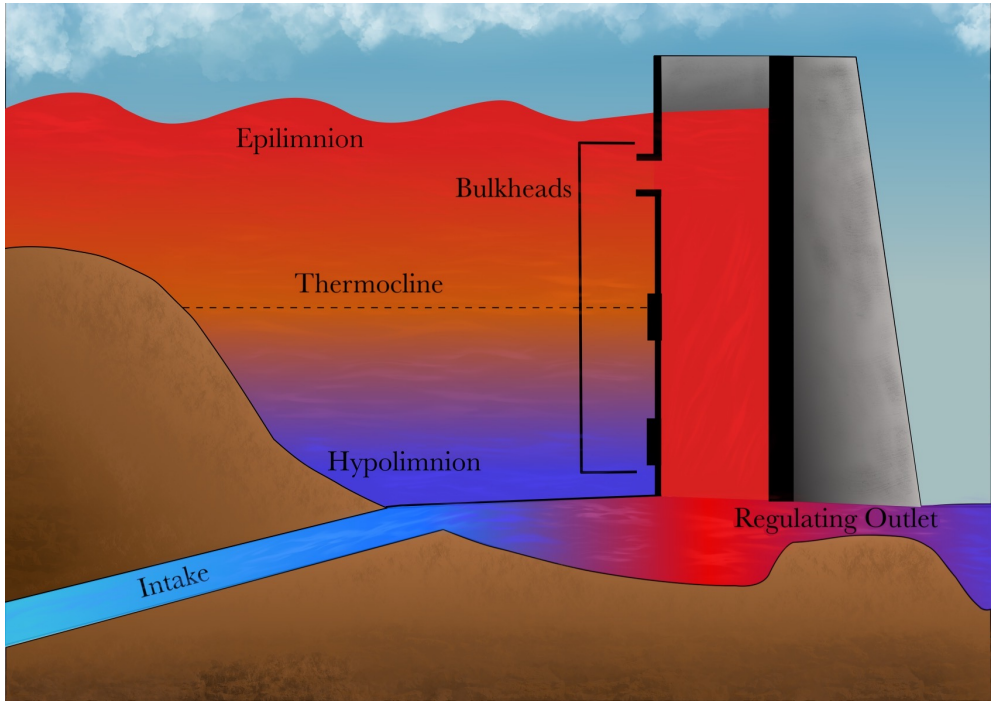
Introduction

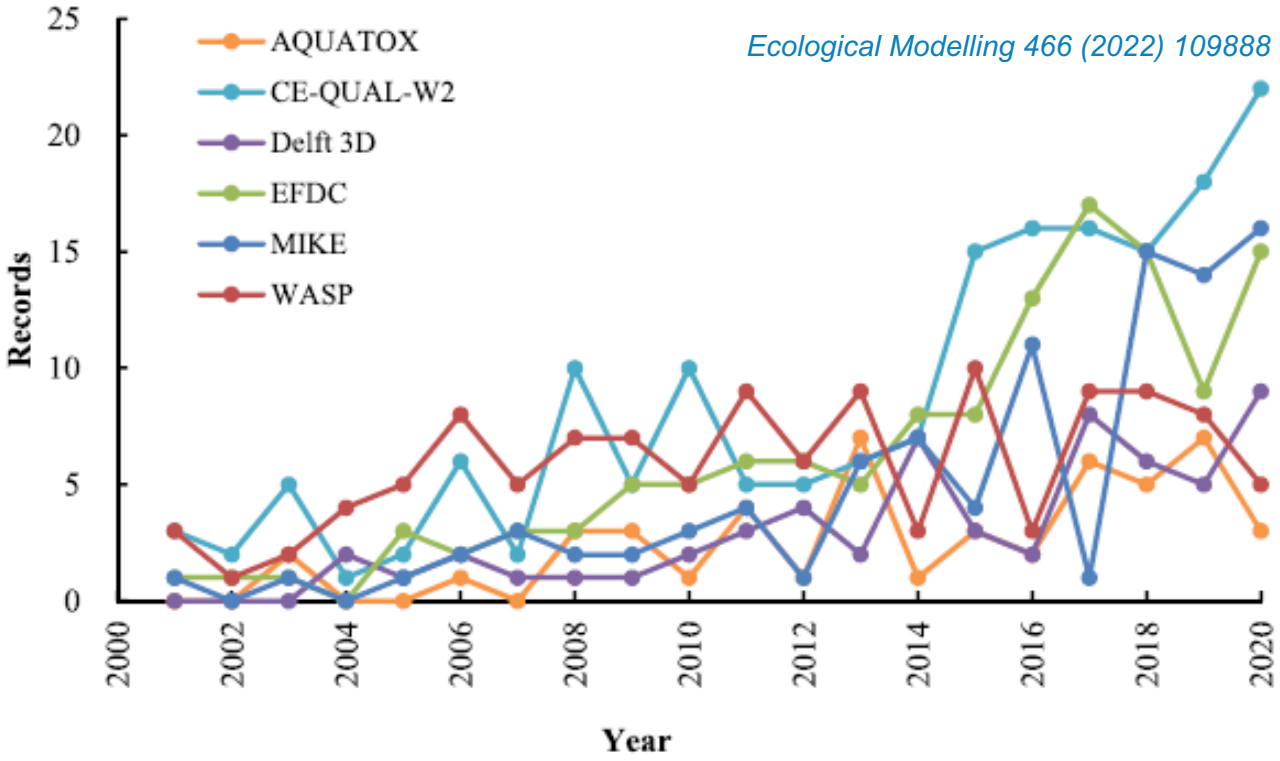
- Problem: Existing models inadequately predict the timing, frequency, intensity, spatial variability, and impacts of Harmful Algal Blooms (HABs).
- Solution: A predictive HAB planning tool is being developed using ERDC's reservoir water quality model, CE-QUAL-W2.



CE-QUAL-W2

- CE-QUAL-W2 (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 has been applied to rivers, lakes, reservoirs, and estuaries.





Ecological Modelling 466 (2022) 109888

CE-QUAL-W2 Capabilities

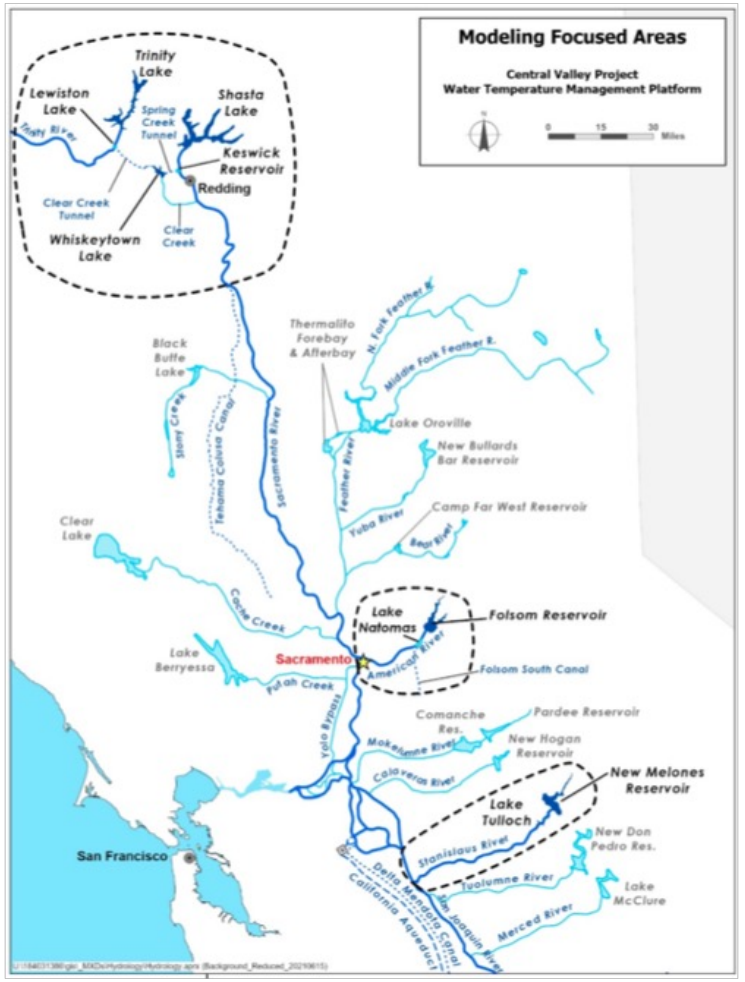
- Longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems
- Nutrients-dissolved oxygen-organic matter interactions
- Fish habitat
- Selective withdrawal from stratified reservoir outlets
- Hypolimnetic aeration
- Multiple algae, epiphyton/periphyton, zooplankton, and macrophytes
- Carbonaceous Biochemical Oxygen Demand (CBOD)
- Sediment diagenesis model
- Generic water quality groups
- Hydraulic structures (weirs, spillways, pipes, culverts) algorithms, including a dynamic shading algorithm based on topographic and vegetative cover.
- Water age – Useful for forensic analyses

Past and Current Applications of CE-QUAL-W2

- CE-QUAL-W2 is widely used by the U.S. Army Corps of Engineers (USACE) and other U.S. federal, state, and local agencies for environmental impact assessments, planning studies, etc. Agencies that use CE-QUAL-W2 as their standard reservoir water quality model include:
  - U.S. Geological Survey (USGS)
  - U.S. Bureau of Reclamation
  - U.S. Environmental Protection Agency (EPA)
  - State of California
- More than 1,100 model applications have been developed worldwide for reservoirs, rivers, estuaries, and other water bodies since CE-QUAL-W2 was released in 1986.
- CE-QUAL-W2 is also used as a research tool by researchers at universities and other organizations.
- At least 1,500 publications utilized or cited CE-QUAL-W2 in the year 2022 alone.

Recent Studies:

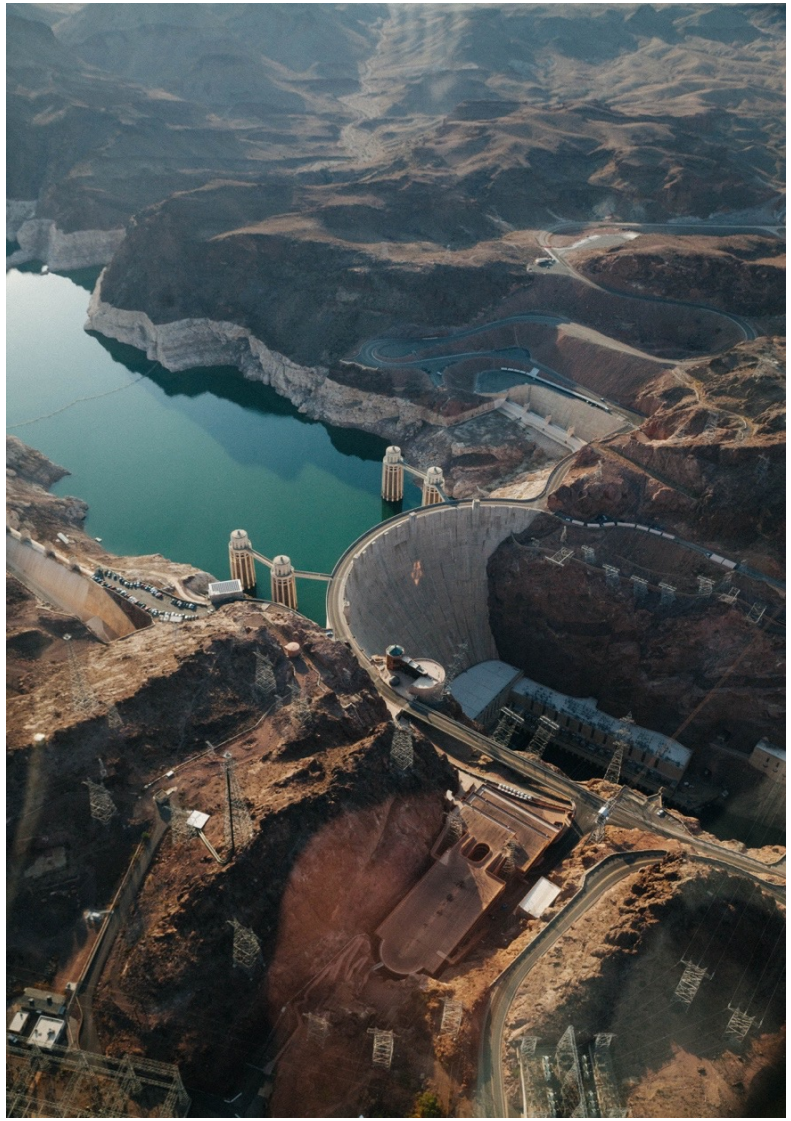
- Water Temperature Modeling Platform, California Central Valley Project (USBR and State of California): This platform applies CE-QUAL-W2 for ongoing and future operations decision-making
- USACE Northwest Division, Columbia and Snake River Watershed
  - ► Columbia System Reservoir Operation (CRSO) Project
  - ► Columbia River Treaty (CRT) Project
- Philadelphia District, Lehigh River Water Quality Modeling



Region of Application:
Water Temperature Modeling Platform
California Central Valley Project

CE-QUAL-W2 Benefits

- Since it was first released in 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



Challenges and Solutions

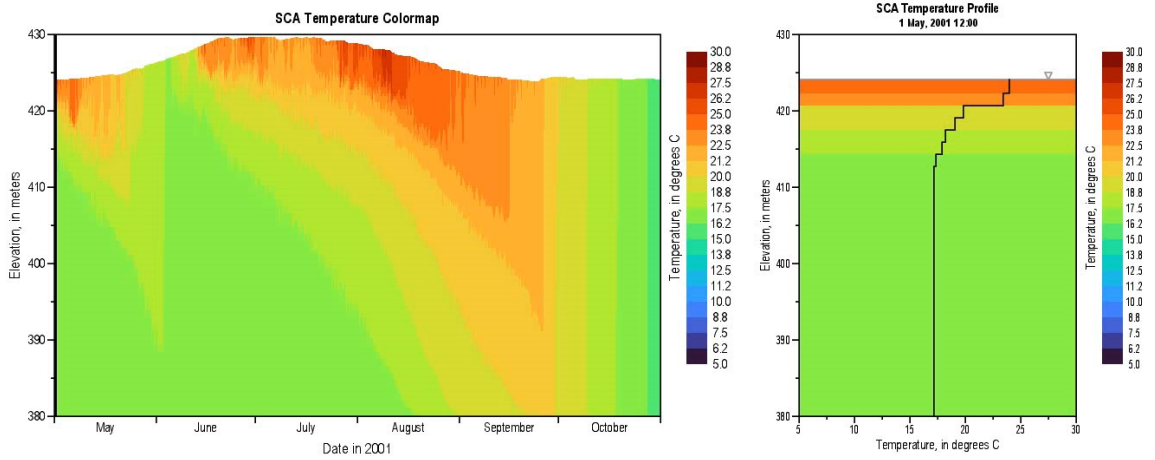
- Developing HAB simulation capabilities applicable to any reservoir is challenging. Reservoirs have characteristics that can vary significantly:
  - Algal species
  - Water body morphometry (length, width, etc.)
  - Volume
  - Depth
  - Mixing dynamics (wind forcing, fetch orientation)
  - Harmful algal blooms can exhibit rapid changes and non-linear dynamics that are difficult to capture in model simulations.
- To address these issues:
  - Extensive literature review. Feedback gathered from HAB experts.
  - Case study site (Detroit Lake, Oregon) was selected to provide adequate data and a range of conditions that enables development of scaling methods.
  - Single species selected for algorithm development. Will serve as a surrogate for prediction.

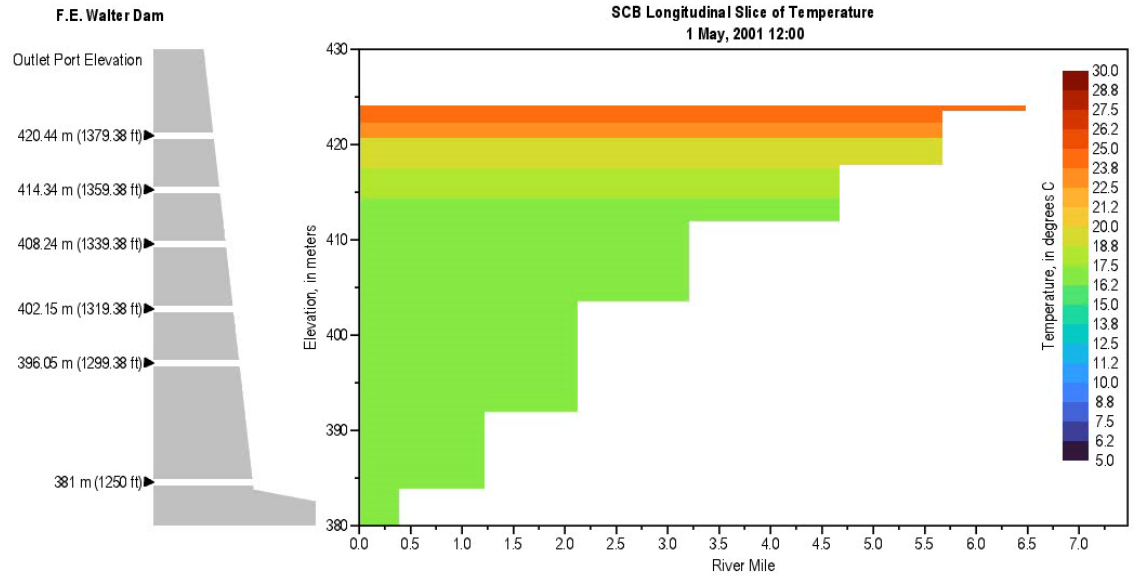
Detroit Lake, Oregon

Detroit Lake HAB

Method and Algorithm Research

- Upwelling and boundary mixing dynamics
  - HABs are not spatially uniform
  - They are controlled by light penetration, temperature, and nutrient availability
  - Investigate the role of boundary mixing and upwelling on light penetration and HAB growth
  - Relate vertical mixing to HAB occurrence and intensity
    - Nondimensional numbers: Schmidt Stability Index, Wedderburn Number, Richardson Number



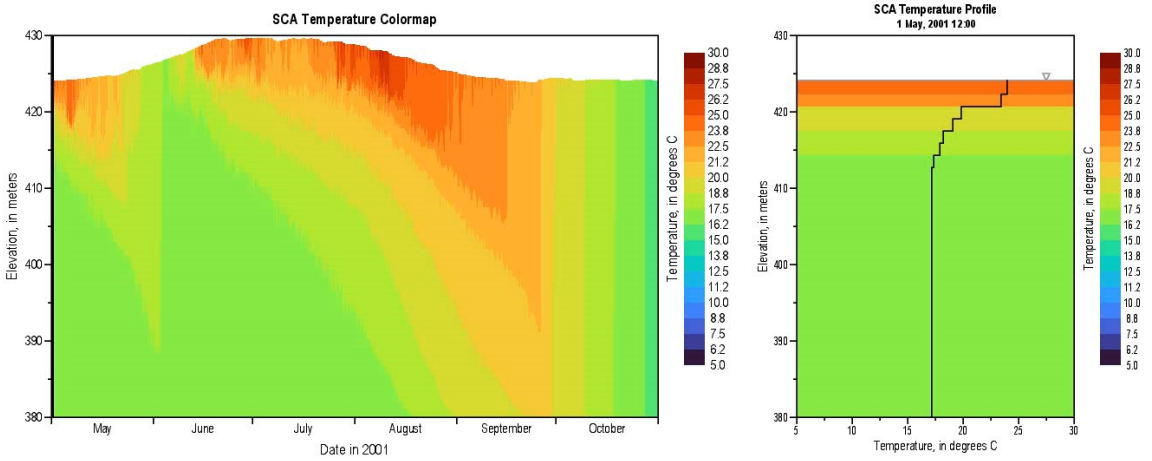


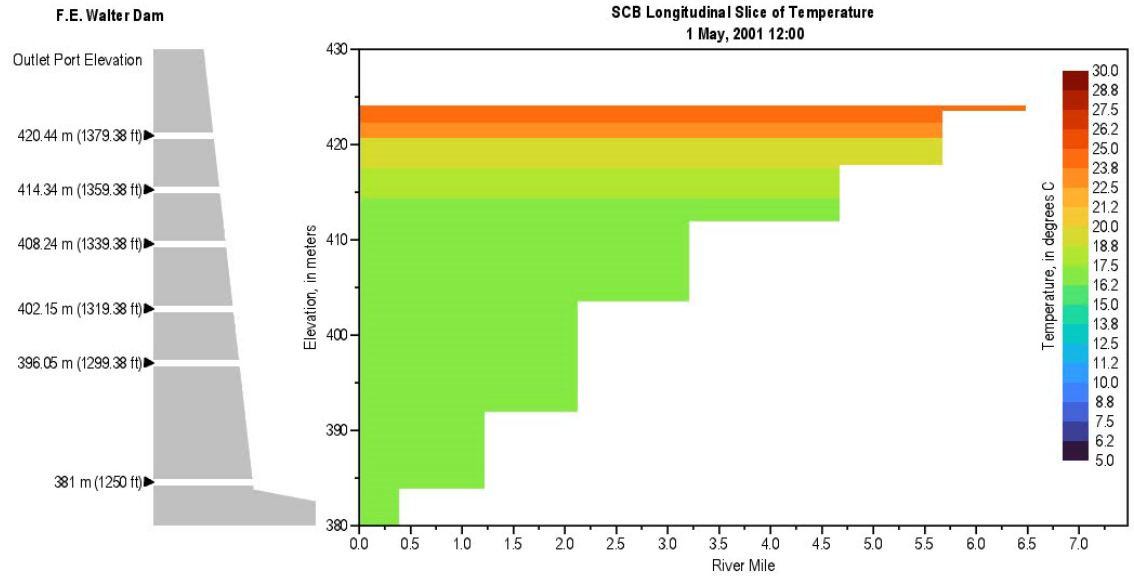
Proposed Improvements

- Improving estimates of parameters (such as maximum growth rate and nutrient half-saturation coefficients) through an updated review of lab and field studies.
- Providing independent kinetics for nitrogen and non-nitrogen fixing species to better represent competition.
- Further application of the cyanotoxin model (Garstecki, 2021).
- Incorporating resuspension or lowering settling velocity as a function of shear in the water flow.
- Improve capabilities to incorporate seasonal algae life cycle.
- Development of a workflow to account for variable chl-a: phytoplankton biomass ratio, based on nutrient and light concentrations.
- Add the ability for algae to move throughout the water column based on changing light, nutrients, and temperature levels, as well as specific algae preference.
- Improve accuracy of interactions between sediment and water column.
- Explore further into the dynamics of competition, with the goal of implementing further competition processes into the model once understanding of these processes is improved.
- Linking to vegetation modules.

Goals

- CE-QUAL-W2 enhancements:
  - Improve buoyancy dynamics, add options, and guidance for use
  - Improve nitrogen fixation algorithms (cyanobacteria may outcompete native algae since they can fix nitrogen)
  - Impose oxygen constraint on algae (per QUAL2K)
  - Prepare guidance on best practices for modeling
- Post-processing prediction:
  - Use CE-QUAL-W2 outputs and observed cross-sectional data (lateral variability) to predict the maximum concentrations and locations of occurrence.
  - Relate HAB occurrence to non-dimensional numbers
    - Schmidt Stability Index
    - Richardson Number
    - Wedderburn Number





Benefits

- CE-QUAL-W2 (W2) will simulate HAB occurrences with greater precision.
- W2 will improve understanding of how various environmental factors contribute to HAB dynamics, enabling more proactive management.
- W2 outputs will help formulate effective mitigation strategies to reduce the frequency and severity of HAB events by targeting identified key contributing factors.
- W2 outputs will facilitate adaptive management practices.
- Improve HAB simulation of multiple future scenarios will improve emergency response and sampling.
- Early detection and management of HABs will help protect ecosystem health and public safety, minimizing the adverse effects on wildlife and human populations.


Questions?