CE-QUAL-W2 WORKSHOP, 2023
INTRODUCTION TO MODELING

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US Army Corps of Engineers

Environmental Systems Modeling Team

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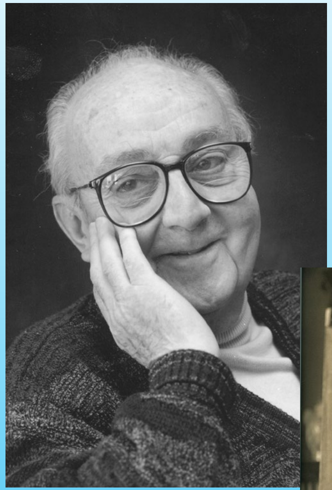
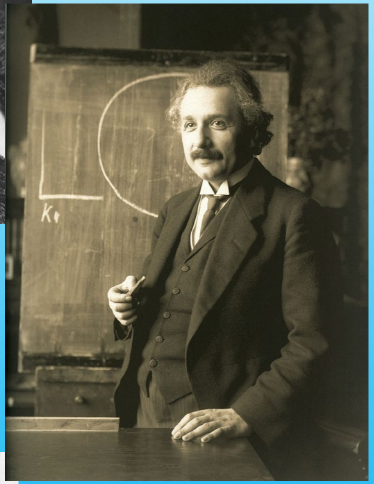
Systems Modeling: Guiding Principles


Albert Einstein, said of his son's career, "He is working on a more difficult problem."

George Box:

... all models are approximations. Essentially, ***all models are wrong, but some are useful.*** *However, the approximate nature of the model must always be borne in mind....*

Paraphrased:

"All models are wrong, but some are useful."

Albert Einstein:

It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.

Paraphrased:

"Everything should be made as simple as possible, but no simpler."

Hans Albert Einstein (Hydraulic Engineer):

You can assume anything you want. The water won't!

Moral: Be careful with your assumptions.

The Tea Leaf Paradox

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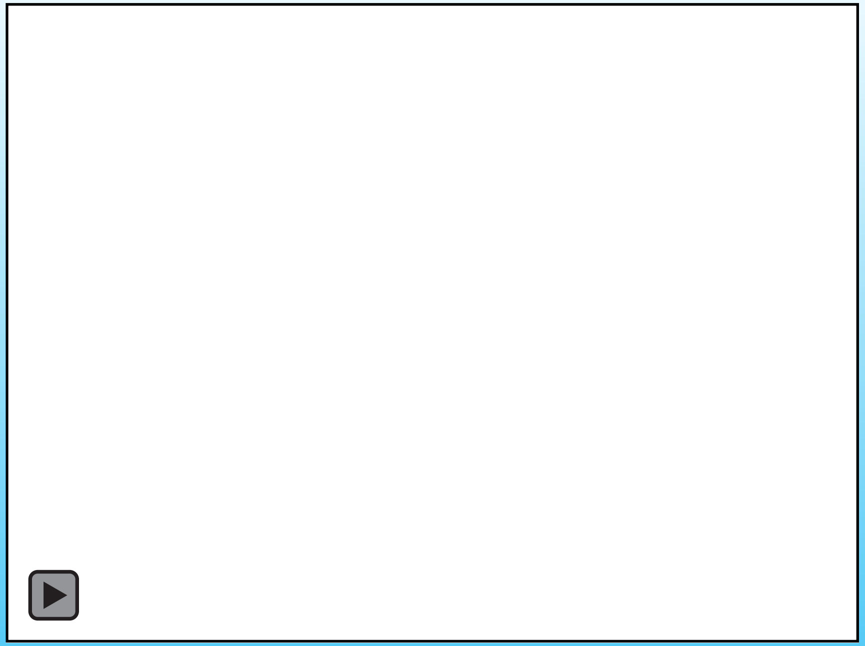

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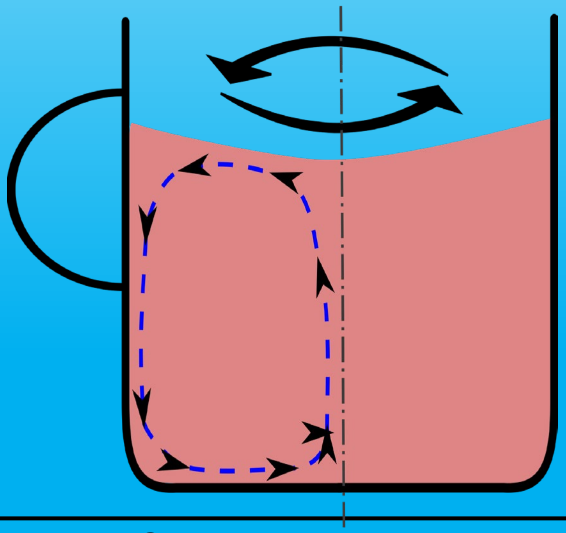

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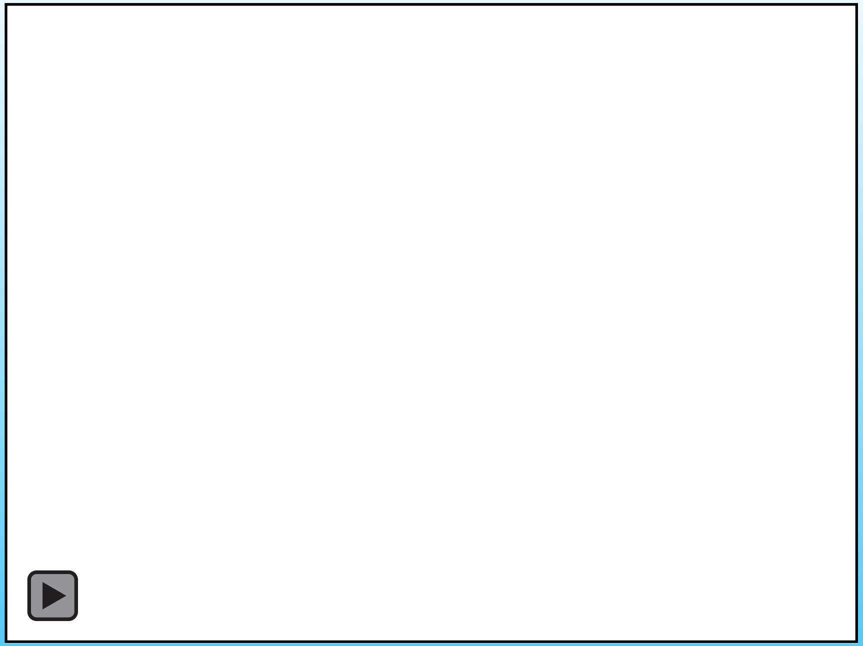
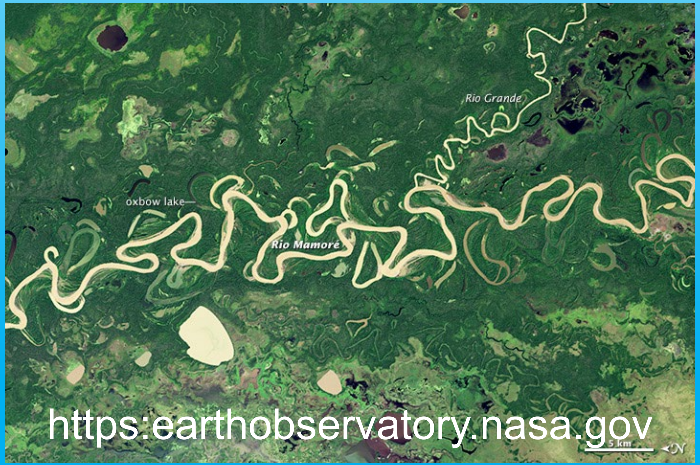
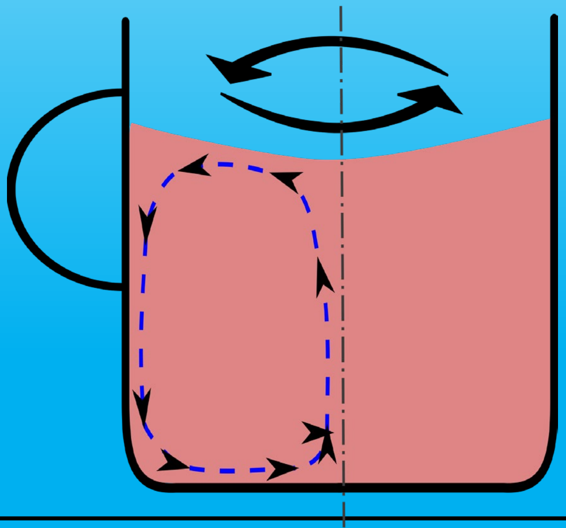


Amazon River, 1985

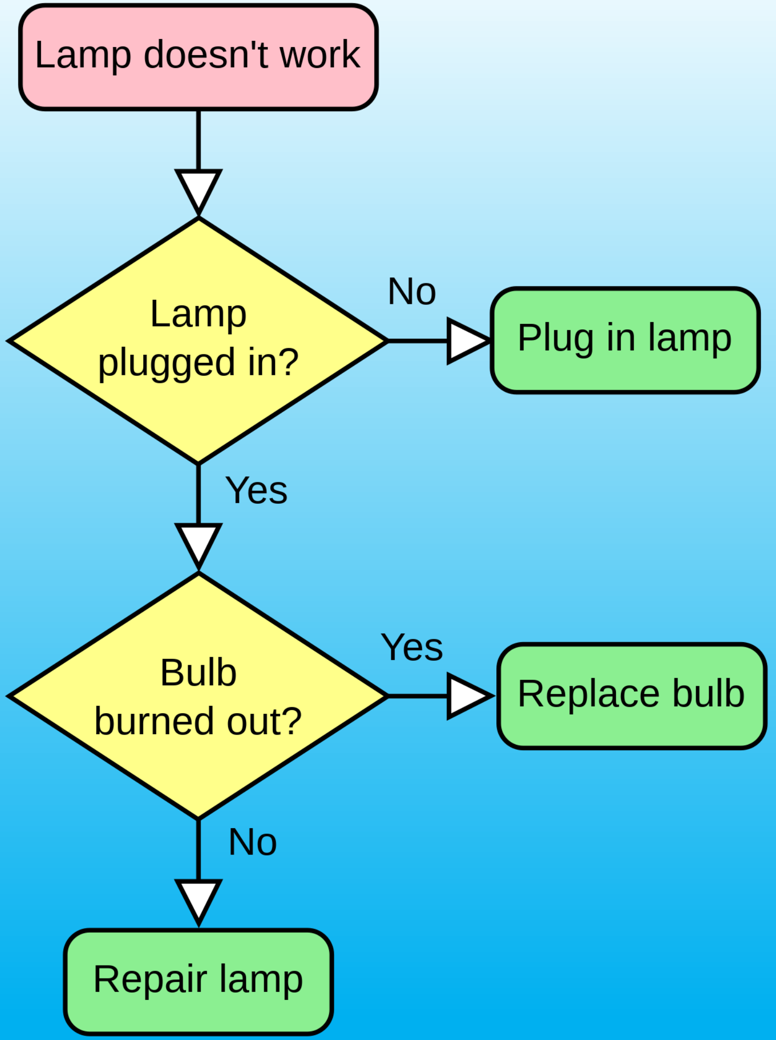


Amazon River, 2014



Modeling Definitions

- Mathematical modeling is the process of developing a mathematical representation of a system using mathematical concepts and techniques to describe the processes, interactions, and parameters of that system.
- Computer modeling is the process of developing mathematical algorithms that describe a system and then developing the computer code to simulate them.
- Modeling vs. Simulation:
  - Modeling is the process of *building* a model
  - Simulation is the process of *using* a mathematical model to study the behavior of a system *for a particular time period*.



Source: https://en.wikipedia.org/wiki/Flowchart

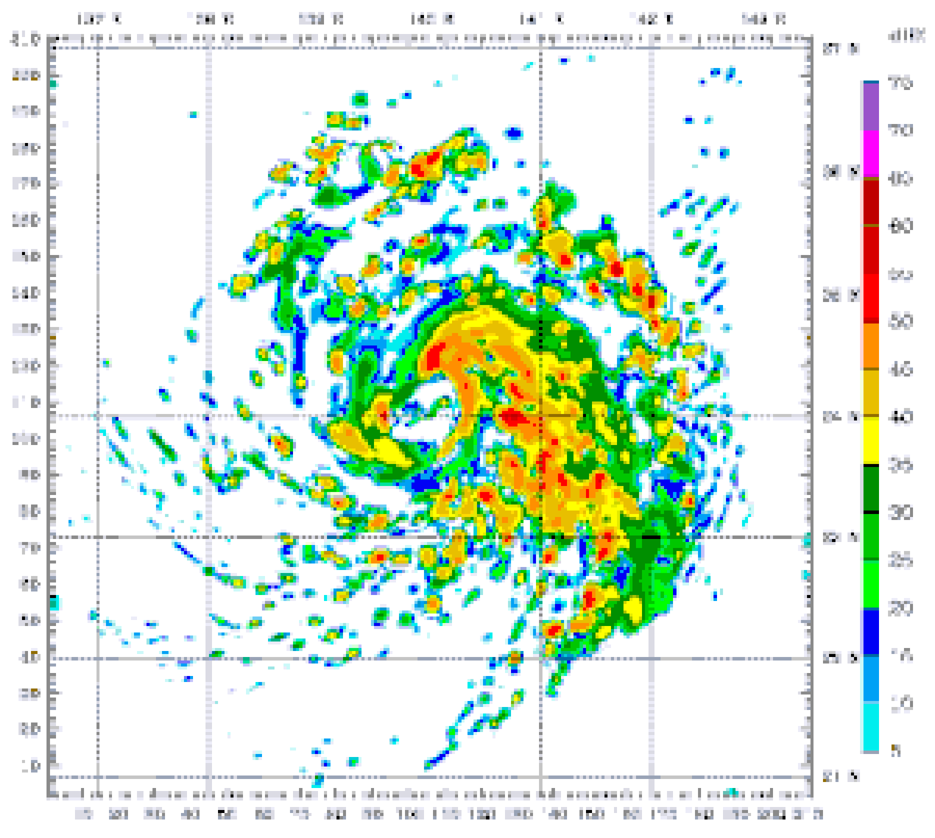
Modeling Definitions

- *Empirical* modeling uses an inductive approach, based on observations (data) and the relationships between system components, such as determined through linear and non-linear regression.
- *Mechanistic* (process-based) models use a deductive approach, based on the principles of physics, chemistry, and biology.
- Most water quality models use a mixture of empirically-derived relationships combined with iterative calculations that describe the physical and biogeochemical processes.

Source: Steven C. Chapra (1997). Surface Water-Quality Modeling. Waveland Press, Long Grove, IL.

Computer Models & Programming

- Early computer models were custom-developed applications programmed for a specific purpose, such as a water quality model of a particular lake or reservoir.
- The first *mathematical* water quality model was developed by Streeter and Phelps in 1925. It predicted the dissolved oxygen "sag curve" in rivers.
- In the 1960's, computer models began to be developed. By the early 1970's, general-purpose models began to emerge.
- Today's general-purpose water resources models, e.g., HEC-RAS, HEC-ResSim, and CE-QUAL-W2, typically do not require the modeler to do any programming.
    - CE-QUAL-W2 is a general-purpose model, but it allows custom computations through modifying and enhancing the *source code*.
    - HEC-ResSim allows custom computations through "scripting." Modelers cannot alter the source code.
    - Scripting (Python, R, MATLAB) is increasingly used for visualization and analysis of the results.



A 48-hour computer simulation of Typhoon Mawar using the Weather Research and Forecasting model.

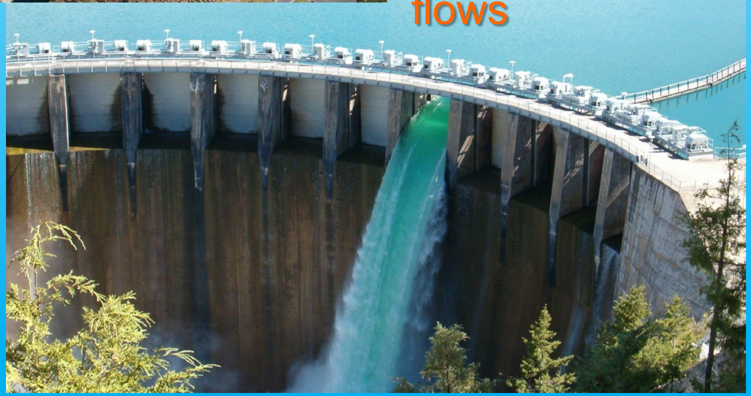
Source: https://en.wikipedia.org/wiki/Computer_simulation

Water Quality Modeling

- Water quality modeling combines mathematical descriptions of the physical and biogeochemical processes to characterize behavior of a waterbody or water resource.
- Water resource and water quality models have been developed to understand and predict the processes in reservoirs, rivers, and watershed runoff.
- The following fields comprise the body of knowledge required for accurate water quality modeling and analysis:
  - Hydrodynamics (physical limnology)
  - Meteorology
  - Aquatic chemistry (chemical limnology)
  - Aquatic biology (biological limnology)
  - Geology (sedimentation, sediment settling, resuspension, and transport)
  - Mathematics and numerical methods
  - Statistics

Flows influence water quality

Water quality must influence flows



Benefits of Water Quality Modeling

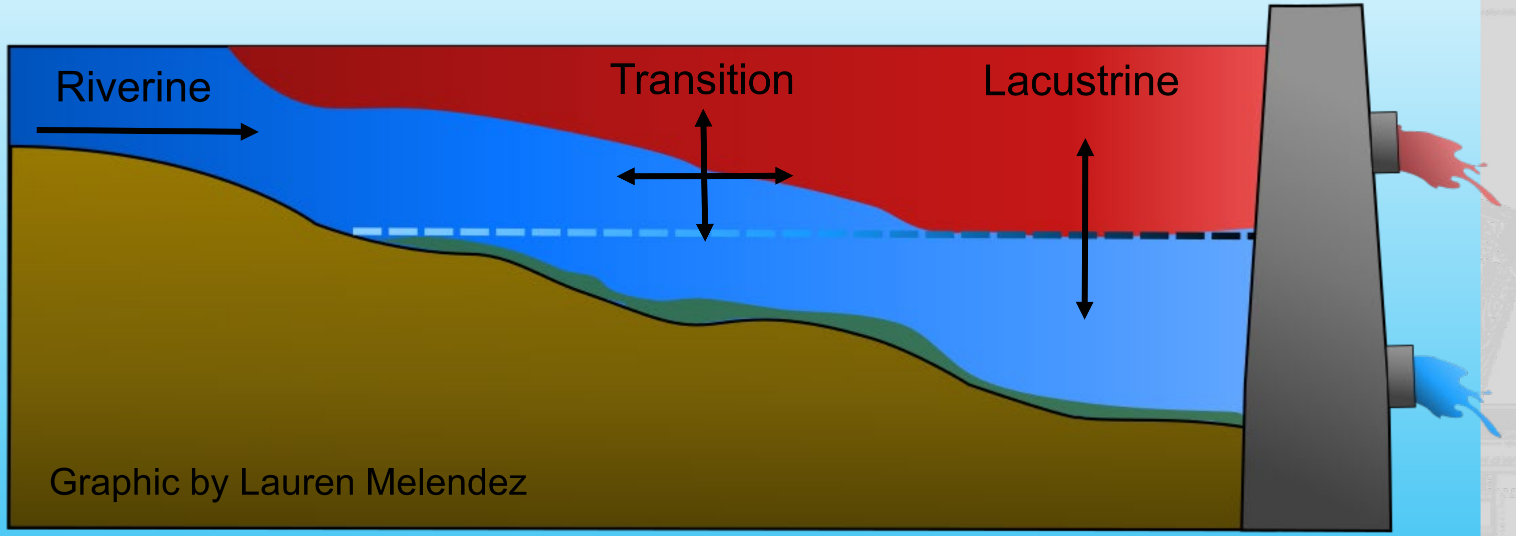
- Interpolation
  - Observed data is sparse in space and time.
  - Interpolation addresses questions like:
    - Where are the best locations for sampling?
    - Where are the most severe water quality problems occurring?
- Extrapolation
  - Forecast water quality in the future.
  - Predict water quality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

Detroit Dam, Oregon

Dworshak Dam, Idaho

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)

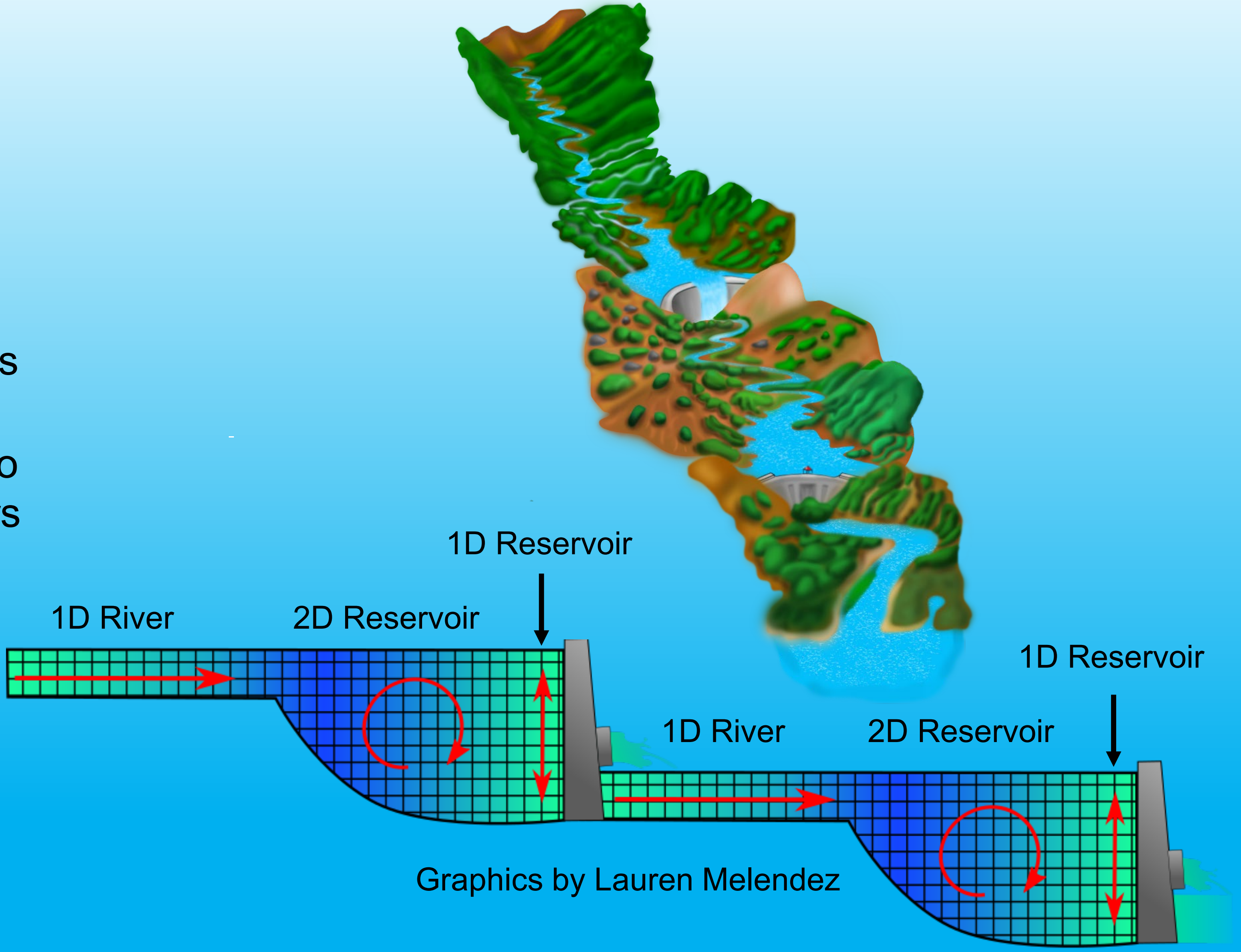


Reservoir system with important flow, WQ, and ecosystem processes for each of three zones.

Notes:
- 1D river model used for channels in a reservoir system
- 2D river model used for floodplain simulation
- 2D reservoir model used for large stratified reservoirs

Model Dimensions, River-Reservoir System

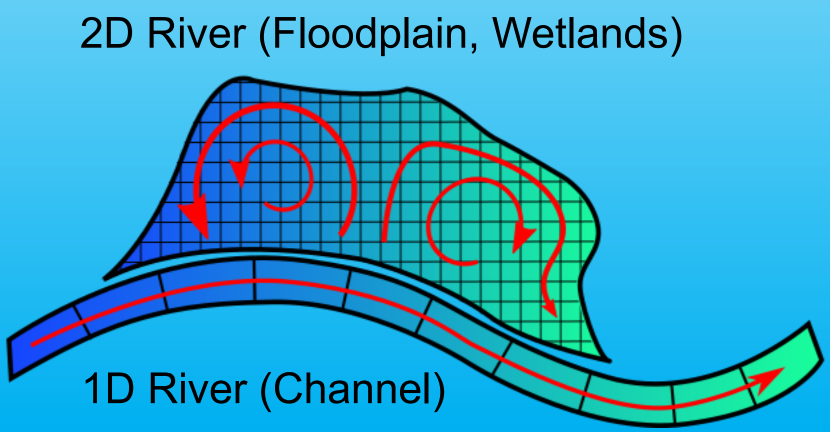
- Unstratified river/reservoir reaches:
  - May be modeled as 1D water bodies (segments)
- Stratified reaches:
  - May be modeled as 1D reservoirs (layers) for real-time release decision-making to meet downstream objectives
  - To characterize and understand in-reservoir processes, reservoirs need to 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)

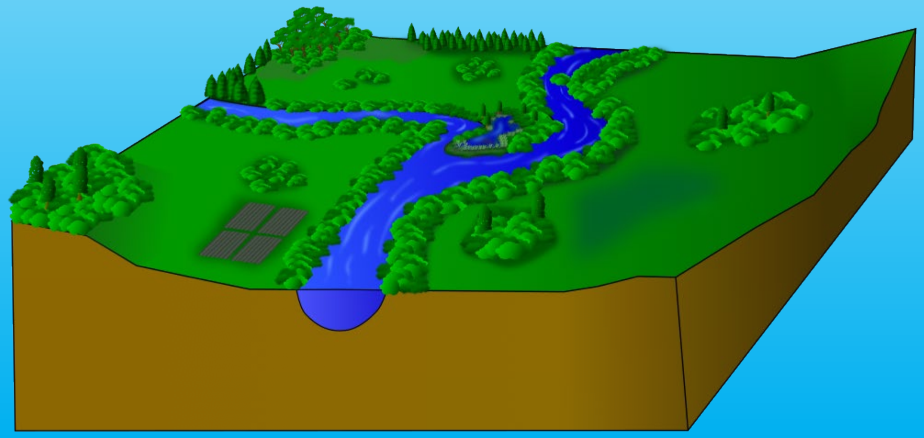


Graphics by Lauren Melendez

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





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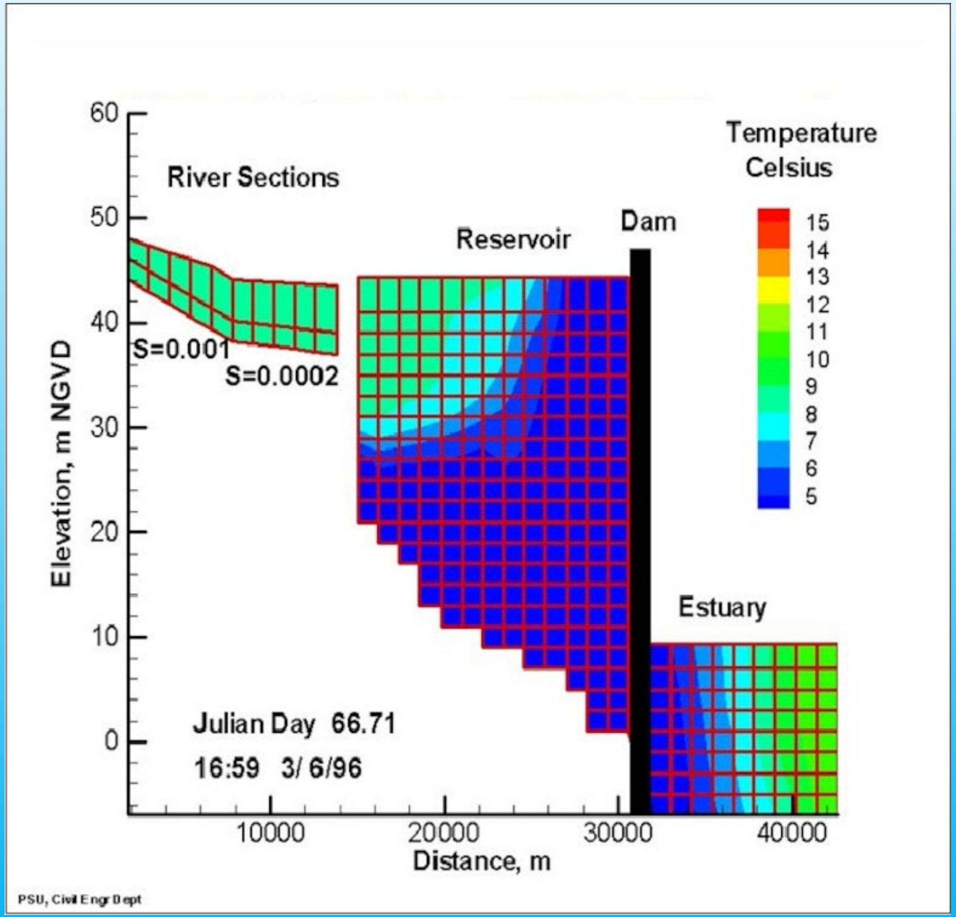
Introduction to CE-QUAL-W2

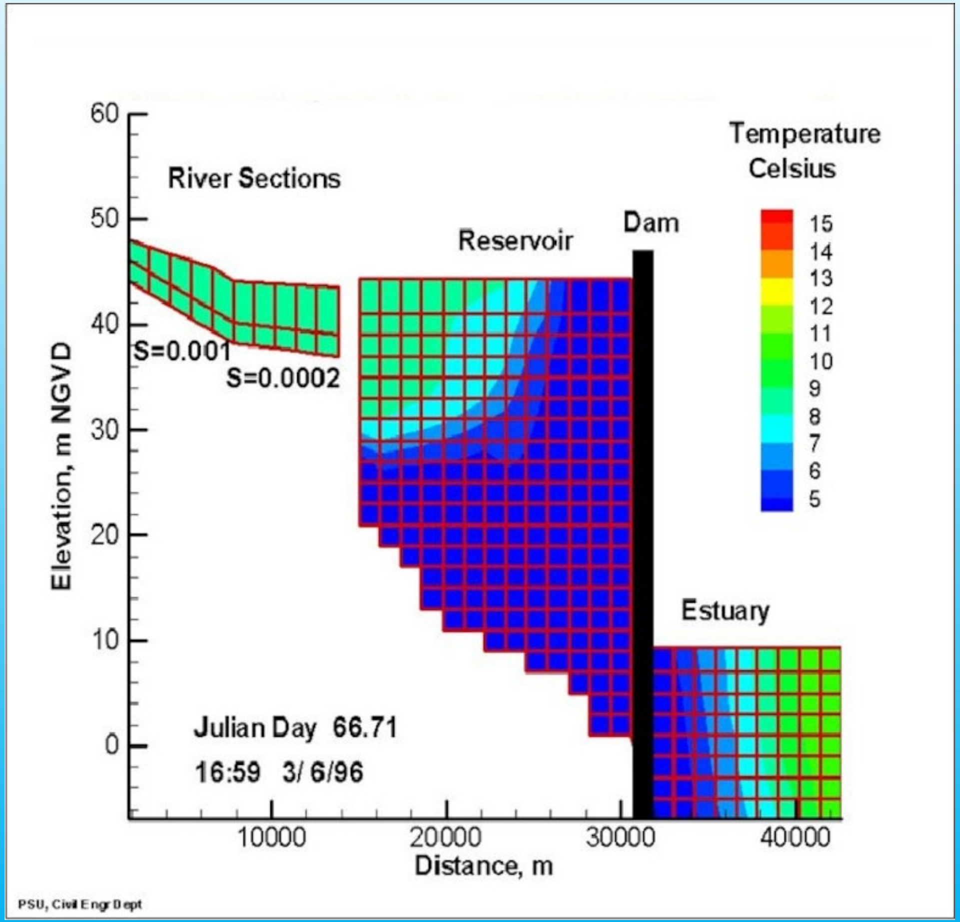
- CE-QUAL-W2 is a two-dimensional (2D), longitudinal/vertical, hydrodynamics and water quality model.
- It enables characterization of the vertical and longitudinal changes in a reservoir.
- The model assumes the reservoir is ”well mixed” laterally, with no variation from one side of the channel to the other in a given layer (vertical) and segment (longitudinal).
- Since CE-QUAL-W2 assumes lateral homogeneity, it is especially suited for relatively long and narrow waterbodies that exhibit longitudinal and vertical water quality gradients.
- CE-QUAL-W2 has been applied to rivers, lakes, reservoirs, estuaries, and combinations thereof.



Longitudinal view of temperature output for a riverine section, reservoir, and estuary, from a CE-QUAL-W2 model application.

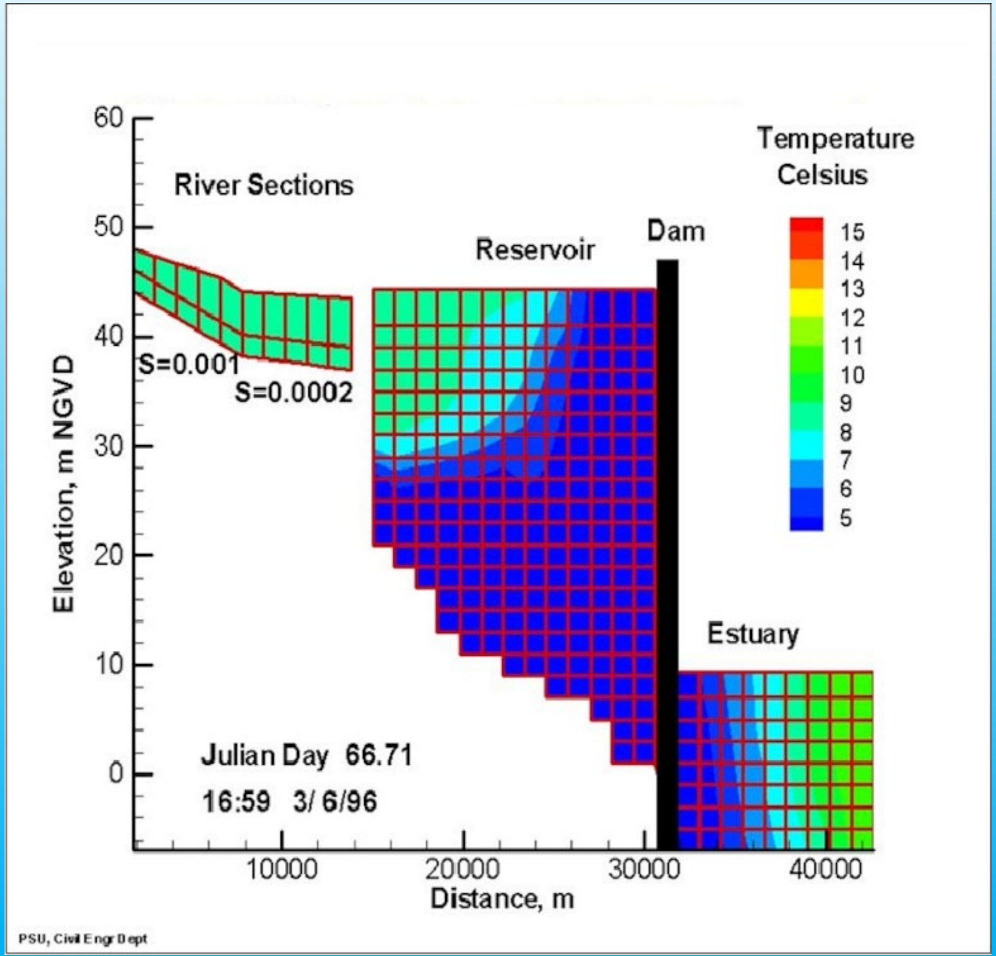
CE-QUAL-W2 Applications

- CE-QUAL-W2 is the reservoir water quality (WQ) model of choice throughout the U.S. and many other countries
- CE-QUAL-W2 is the two-dimensional (2D), longitudinal/vertical hydrodynamic and water quality model of choice for the following agencies:
  - U.S. Army Corps of Engineers (USACE)
  - U.S. Geological Survey (USGS)
  - U.S. Bureau of Reclamation (USBR)
  - U.S. Environmental Protection Agency (EPA)
  - Tennessee Valley Authority (TVA)
- There have been more than 300 applications worldwide of CE-QUAL-W2
- Cited in more than:
  - 15 PhD dissertations
  - 50 Master's theses
  - 100 presentations at scientific meetings
  - 20 journal articles worldwide



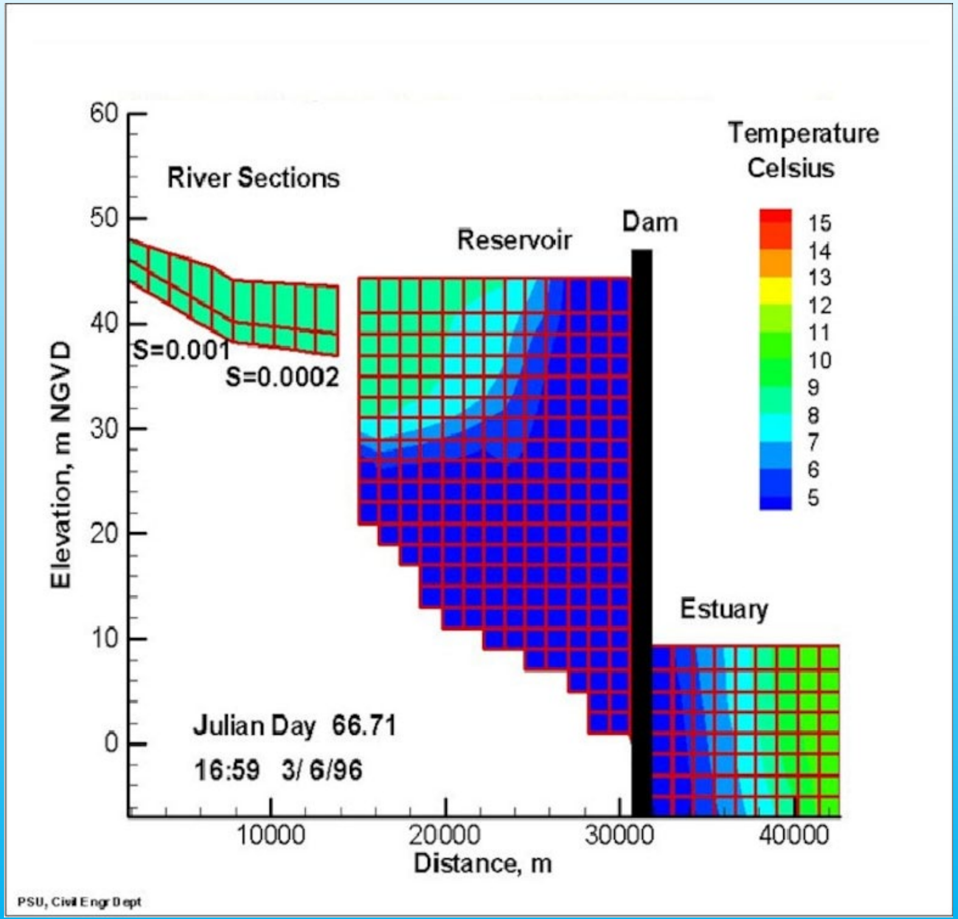
CE-QUAL-W2 Capabilities

- Longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems
- Interactions between nutrients, dissolved oxygen, and organic matter
- Fish habitat volume
- Selective withdrawal from specially design outlets to provide cold-water releases from stratified reservoirs
- Hypolimnetic aeration
- Multiple algae, epiphyton/periphyton, zooplankton, and macrophyte groups
- CBOD
- Sediment diagenesis model
- Generic water quality groups
- Internal dynamic pipe/culvert model
- Hydraulic structures (weirs, spillways) algorithms



CE-QUAL-W2 Capabilities, Continued

- The hydraulic structures algorithms include submerged and two-way flow over submerged hydraulic structures as well as a dynamic shading algorithm based on topographic and vegetative cover.
- Variable density as affected by temperature, salinity, Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) to simulate stratified flow.
- 28 water quality constituent state variables
    - Any combination of constituents can be included or excluded from a simulation.
    - The effects of salinity or total dissolved solids/salinity on density, and thus hydrodynamics, are included only when simulated in the water quality module.
    - The water quality algorithm is modular, allowing constituents to be easily added as additional subroutines.



Acknowledgements

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- Ecosystem Management and Restoration Research Program (EMRRP)
- Aquatic Nuisance Species Research Program (ANSRP)

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Questions?