

An aerial photograph of a winding river flowing through rolling green hills. The river is a deep blue color, contrasting with the vibrant green of the surrounding landscape. The hills are covered in grass and have a soft, undulating appearance. In the distance, more hills and a range of mountains are visible under a clear sky. The overall scene is peaceful and scenic.

# *REALM*

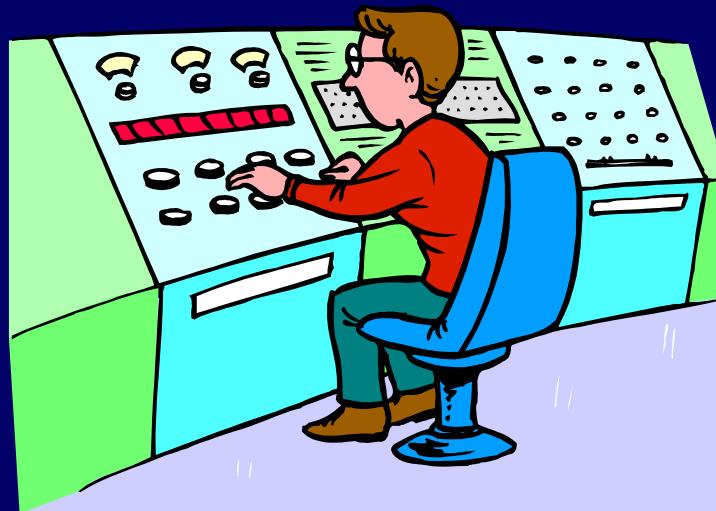
## **River, Estuary, and Land Model**

# Why a New Model?



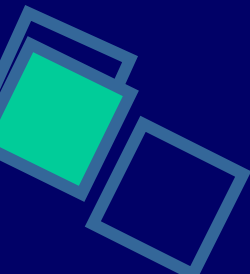
# Need:

- To move beyond one-run simulations of existing and planned scenarios
- To examine range of engineered control of Delta

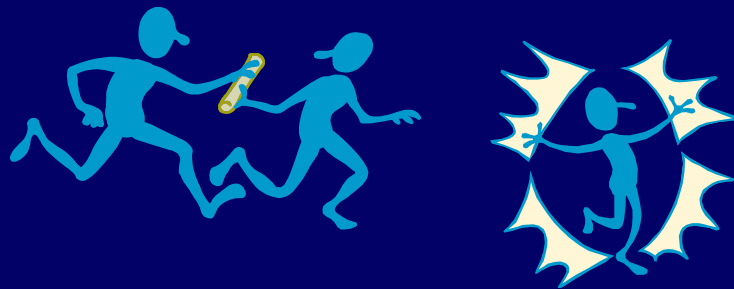




# Need:



To easily adapt  
between large-scale  
and fine-detail  
features

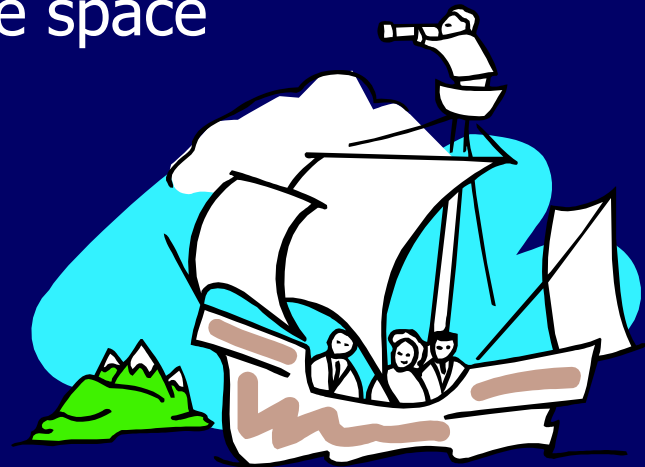


Breakthrough in computing  
speed and accuracy for  
complex problems



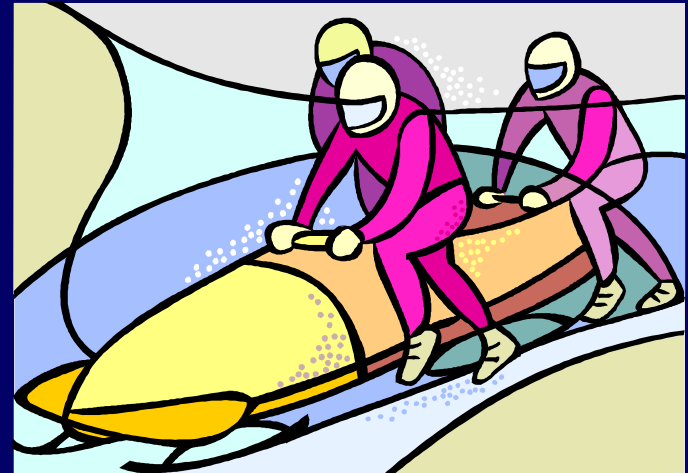
# Current Situation

- Models best for simulation of a single alternative
- Exploration of alternative space difficult



# Current Situation

- Little or no use of speed enhancements:
  - Parallel processing
  - Adaptive mesh refinement

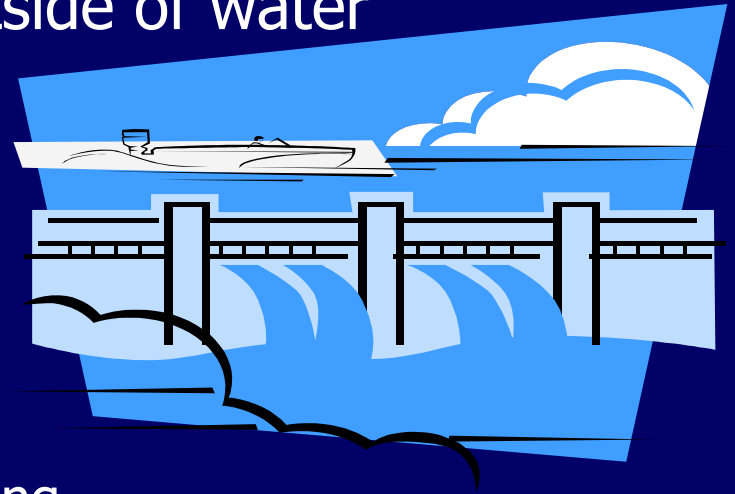




# Current Situation

- Little use of techniques outside of water resources:

- CFD methods
- GIS
- Software/Database engineering



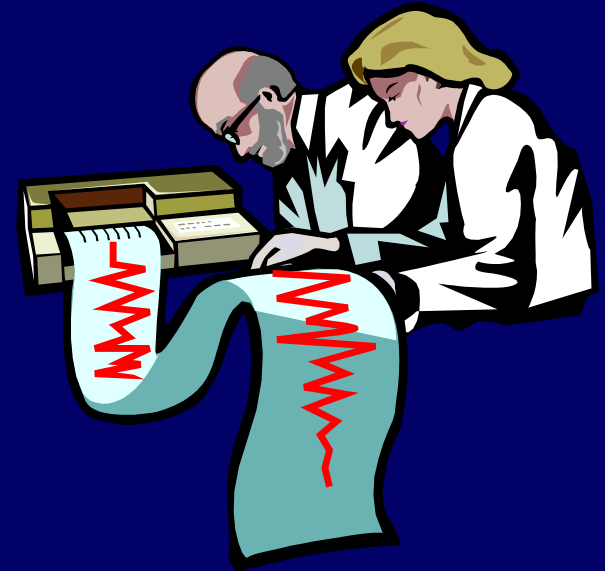
# What's Changed?

- Powerful single and parallel-computing clusters available
- Advanced computing techniques developed at LBL, National Labs, and elsewhere



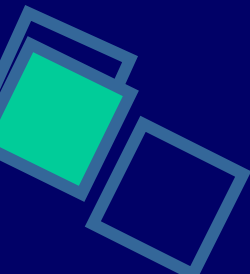
# What's Changed?

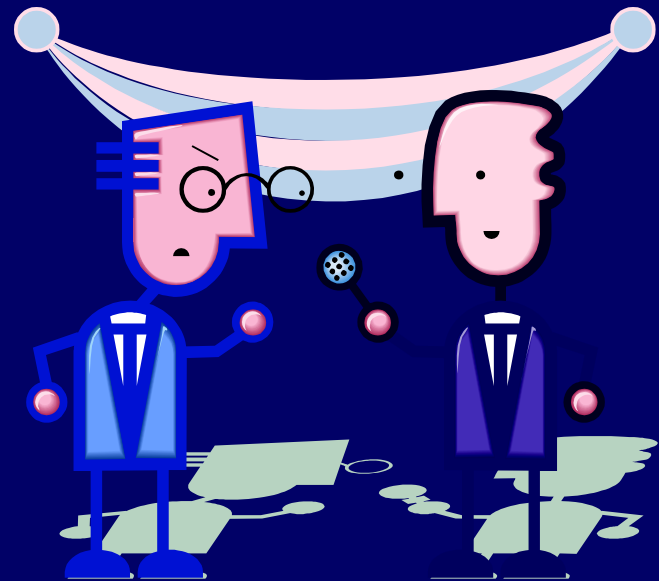
- Much greater quantity and quality of observed data
- Other advances in GIS, data management, and optimal control





# Prologue

- 
- Wide range of Delta workers interviewed
  - Surprising interest in assistance with workers' tasks
  - Strong need shown for accurate, practical models





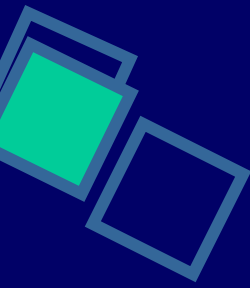
# Feature Requests



- Accurate, Delta-wide Particle Tracking
- Wetting-Drying (tidal/seasonal)
- Designed control of Delta structures (island flooding, pumping, gate operations)



# What will REALM model?

- 
- 2D hydrodynamics and water quality (eventually, mixed 2D-3D)
  - Particles
  - Shallow water equations with viscous momentum terms
  - Irregular boundaries, wetting and drying
  - Arbitrary source terms (friction, Coriolis, reaction kinetics)



# Design Principles

- No Burnt Bridges
- Solicit End-User Requirements (repeatedly)
- Solicit techniques from other fields:
  - Software / Database
  - Engineering control
  - GIS
  - CFD



# Collaboration



## DWR

- Estuary physics and Chemistry
- Optimal control/Data Assimilation
- Data & Time Series Management

## LBL

- High performance
- Software frameworks
- Visualization and steering
- Optimization solvers

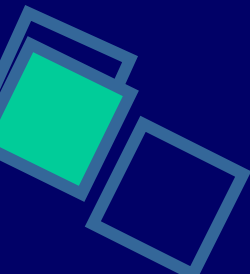


## GIS

- Geographical Data
- Grid Visualization
- Run Preparation
- Output Analysis

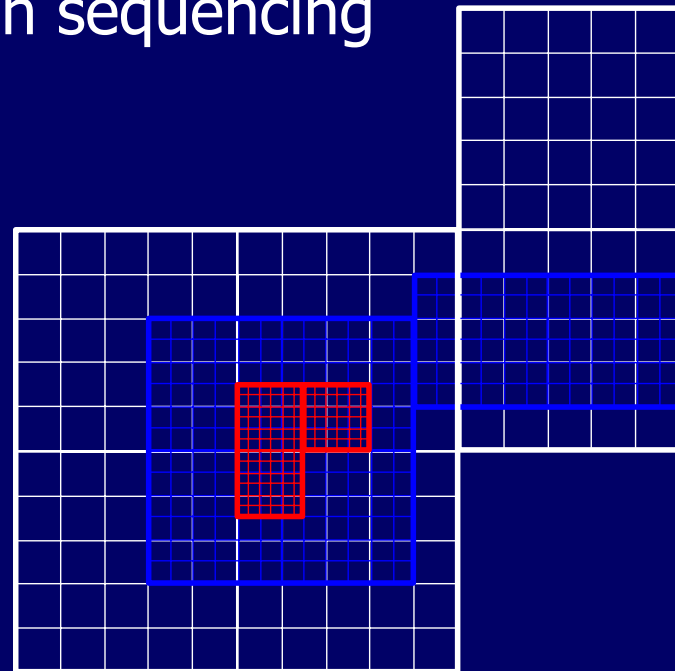
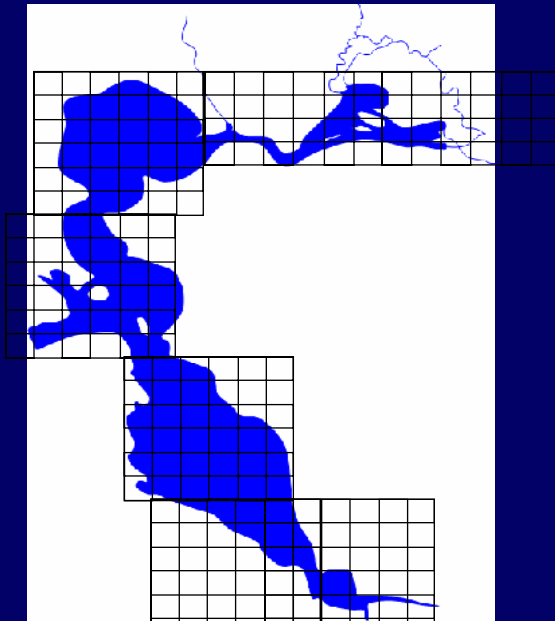


# REALM Numerical Methods

- 
- Finite volume and differences
  - Cartesian grids
  - Emphasize high resolution (e.g. 2<sup>nd</sup> order Godonov) methods, retrench as necessary
  - Revisit conventional wisdom in light of new computing environment

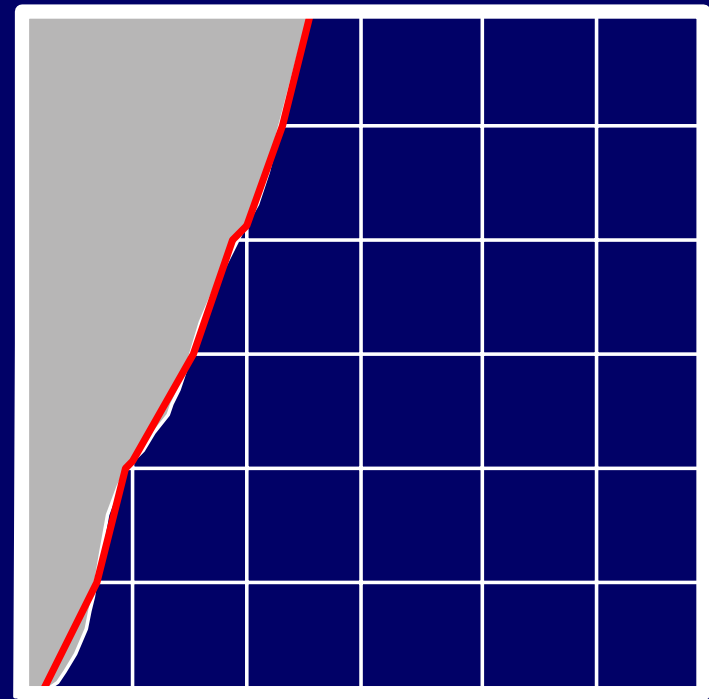
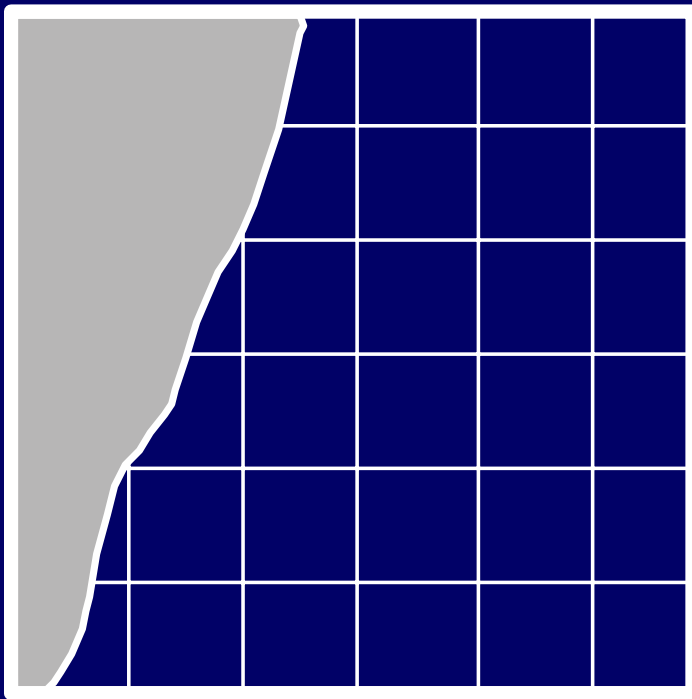
# Adaptive Mesh Refinement (AMR)

- “Minimum” effort for given accuracy
- Much easier user set-up
- (Non-adaptive) Used for “close ups”
- Optimization with mesh sequencing





# Embedded Boundaries



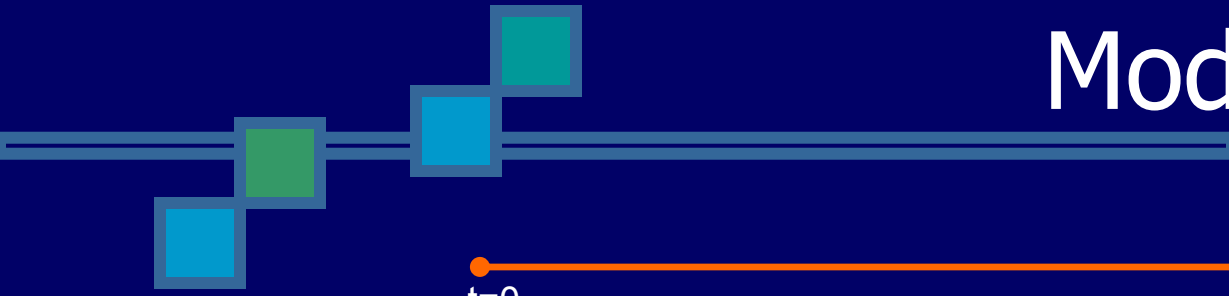


# AMR + EB + Parallel = Hard

- Many small messages
- More complex data structures
- Locality and load balance trade-off is hard
- Don't do this at home, kids!



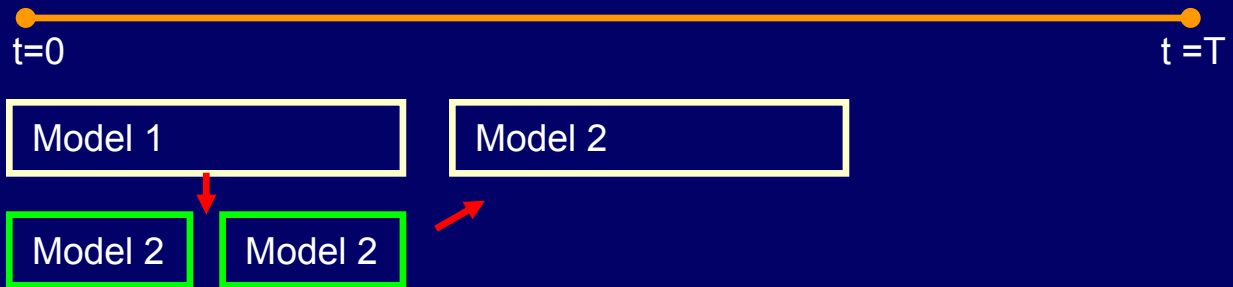
# Model Coupling



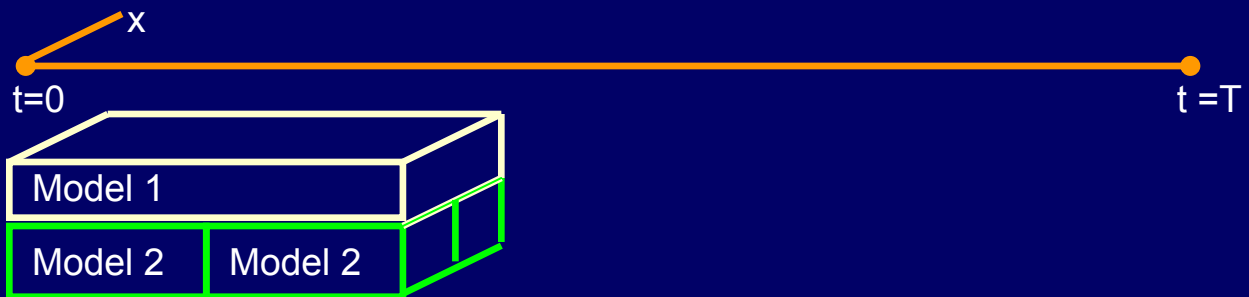
Simplest



Medium

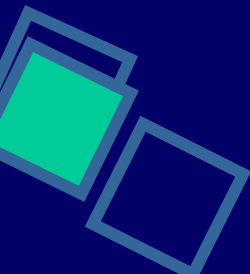


Hardest



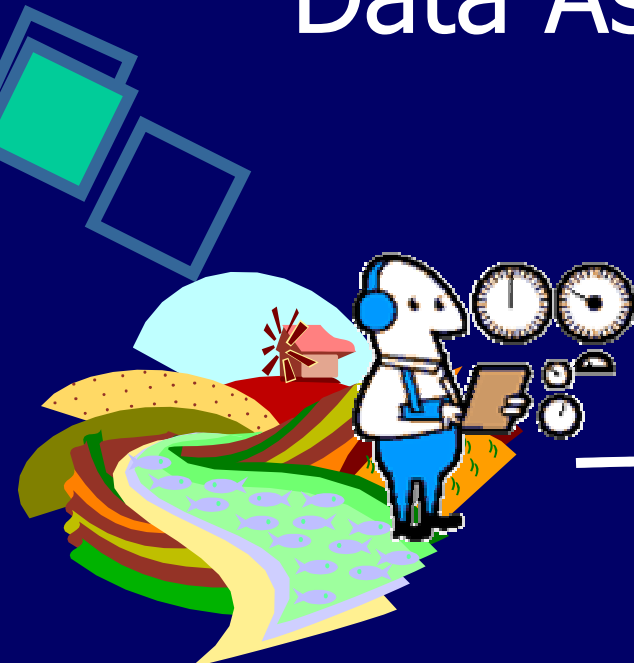


# Decision-Making Support

- 
- Model steering and interactive simulation
  - Real-time data assimilation
  - Adjoint-supplied gradients
    - Optimization and automatic calibration
    - Multi-objective simulation

# Data Assimilation

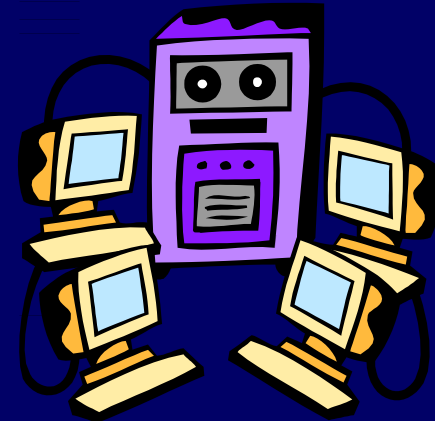
Models With Error



Noisy Data

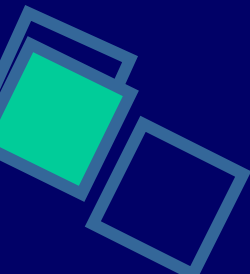


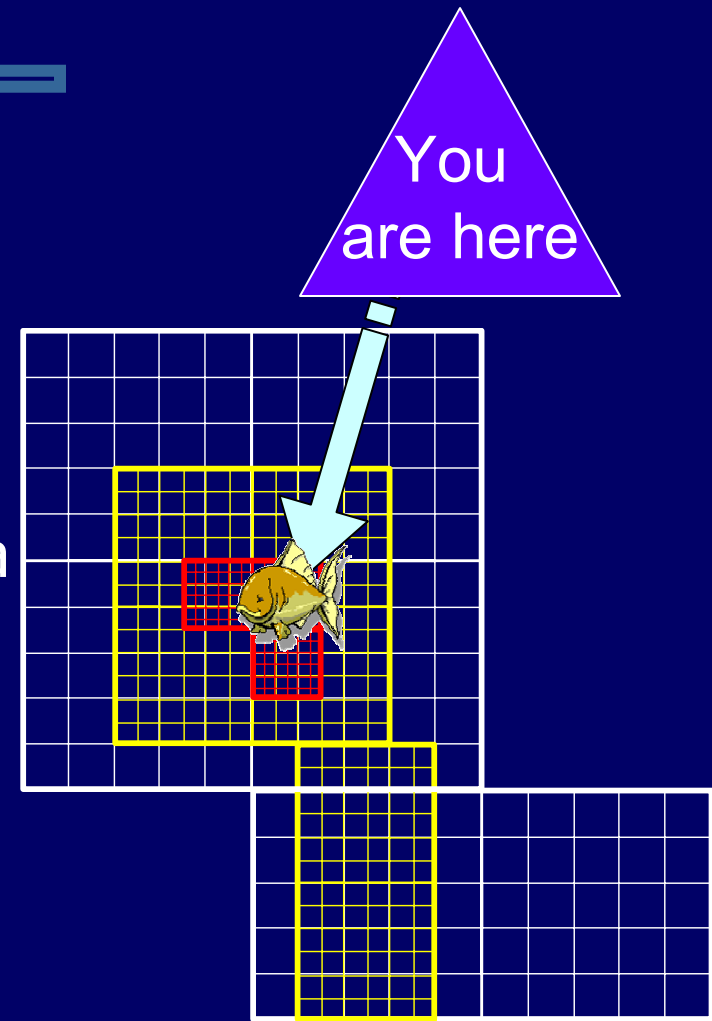
Extended Kalman Filter/  
Adjoint Data Assimilation



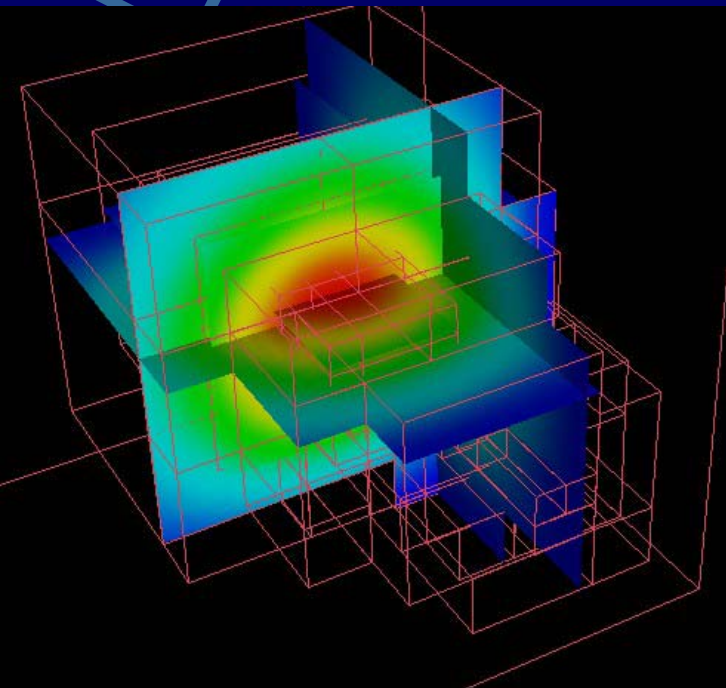
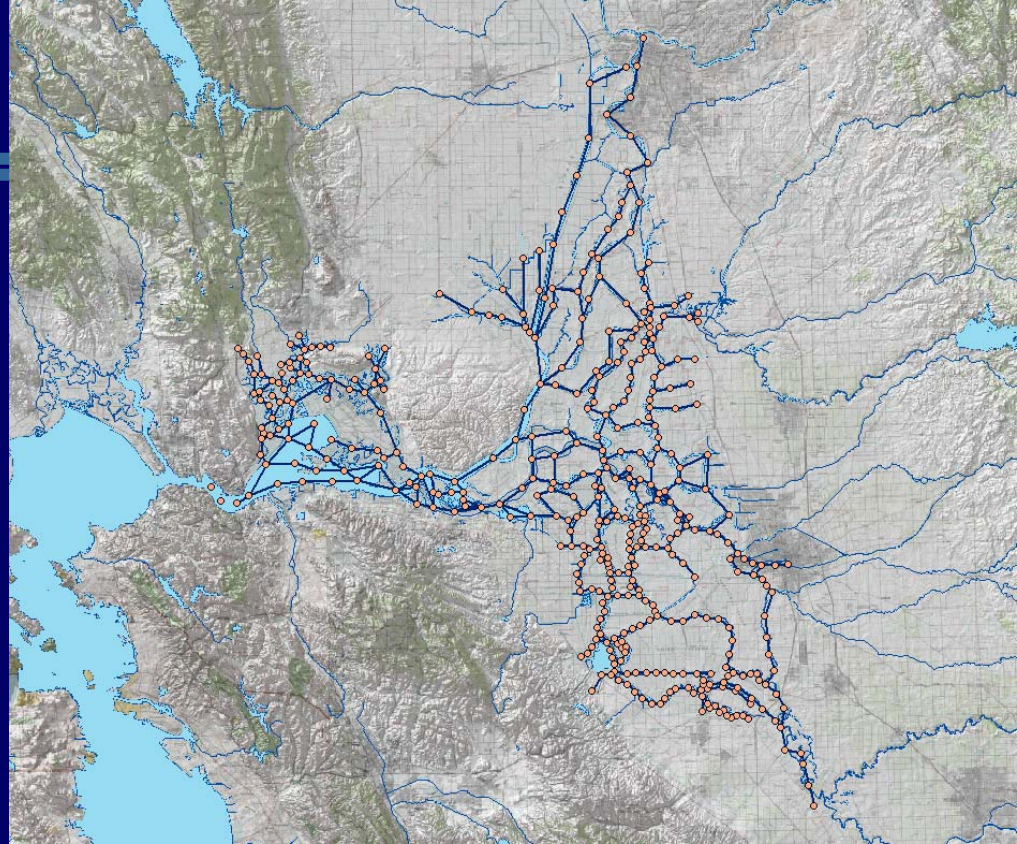


# Example: Particle Tracking

- 
- Track particles through Delta
  - Adaptive grid for high local accuracy
  - Passive + Behavior
  - Steering! Be the smelt



# Visualization

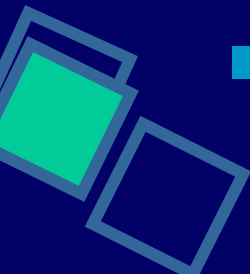


- Interactive Interface
- Production Graphics
- Spatial + Time Series
- Emphasize standards: GIS + HDF5

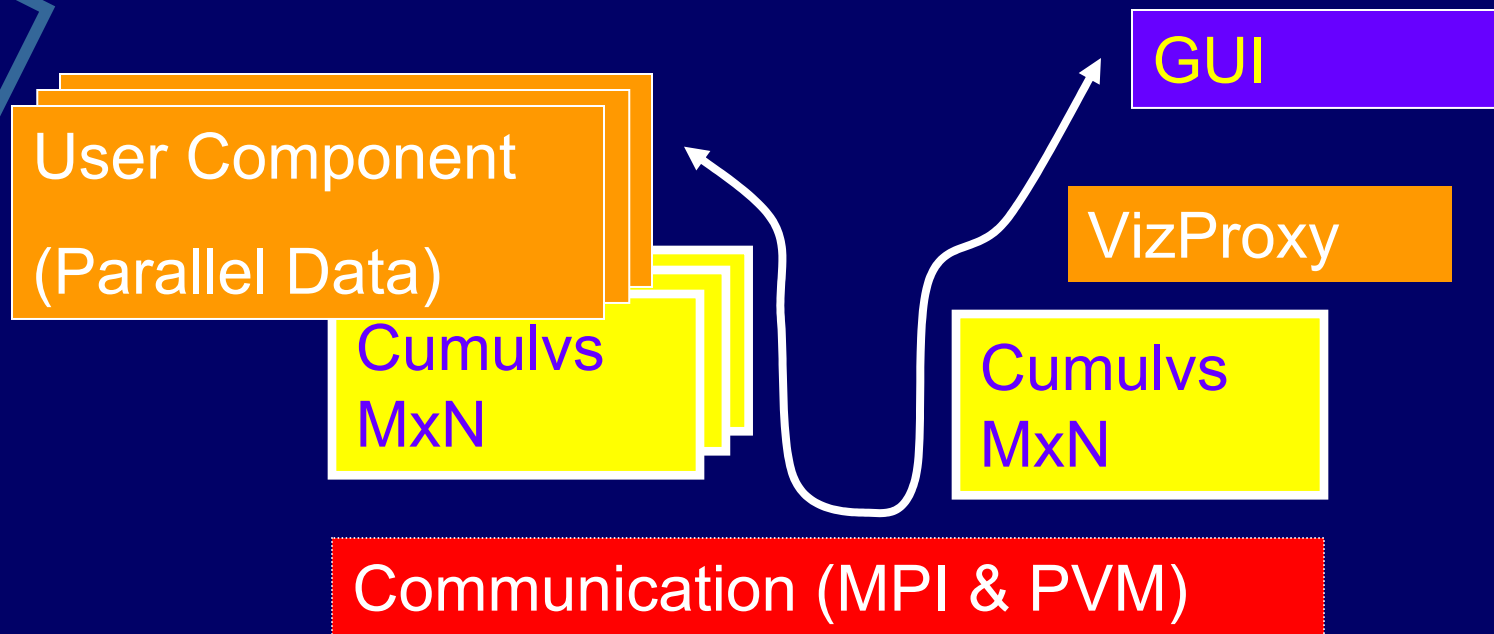


# Steering



- 
- Steering uses an interface to “compiled assets.”
    - GUI/GIS, Python, ....
  - Rich command structure lets users “program” within simulation paradigm
  - Exploit interactivity
  - Mixed architectures OK
  - The tricky thing is parallelism BUT ...

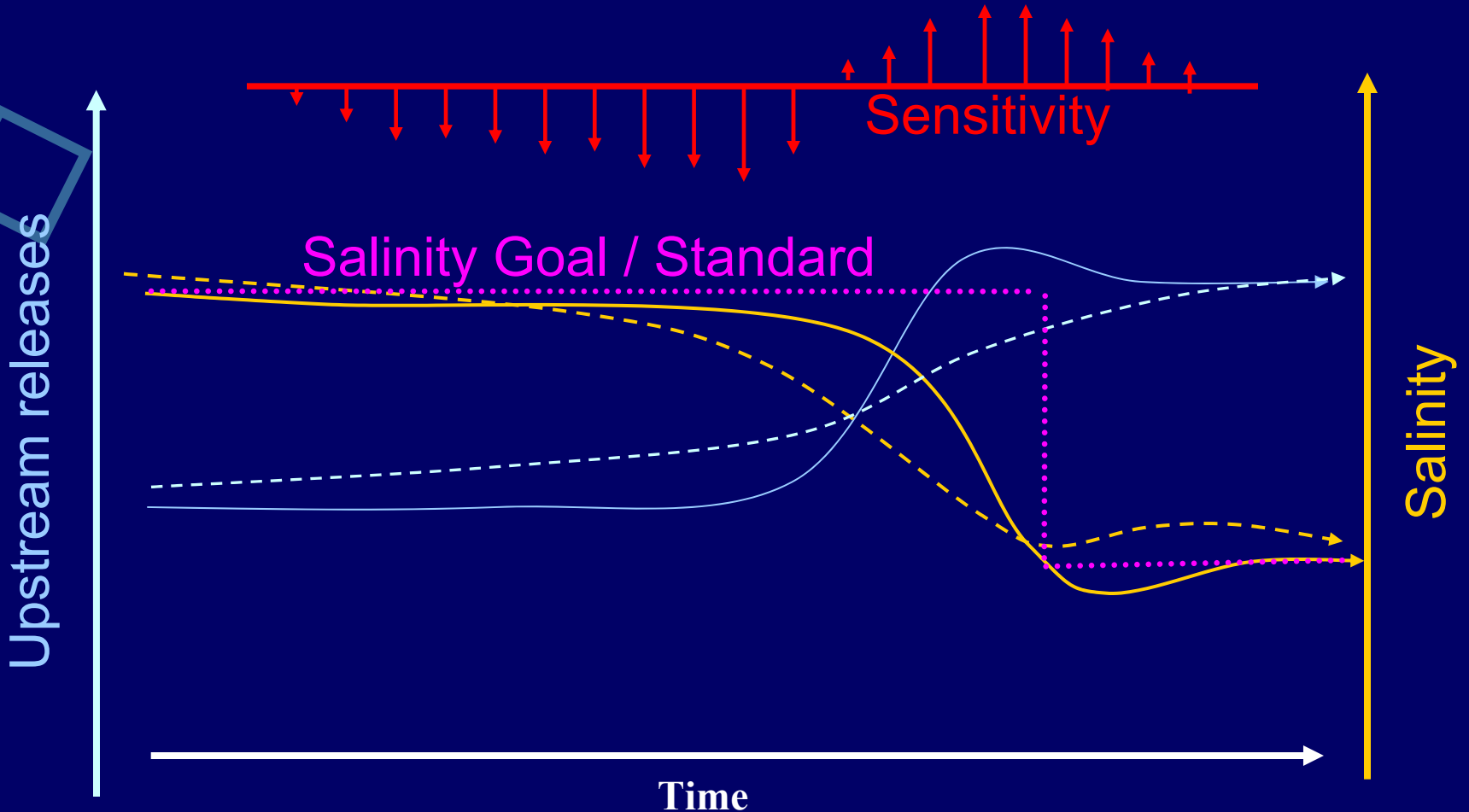
# Cumulvs Framework for Model Steering/Visualization



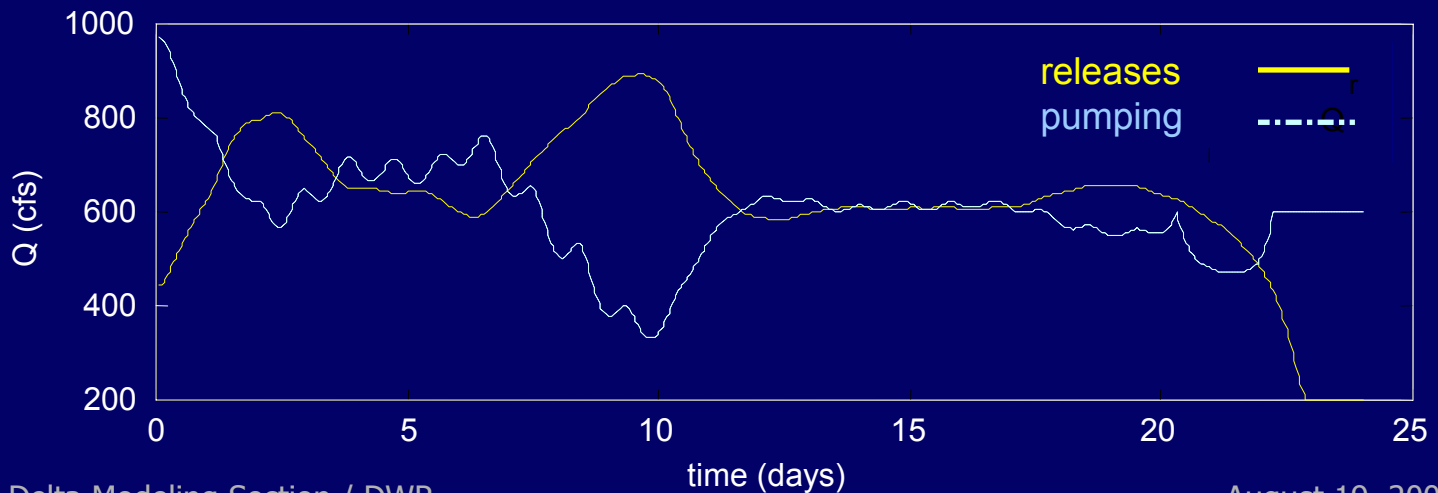
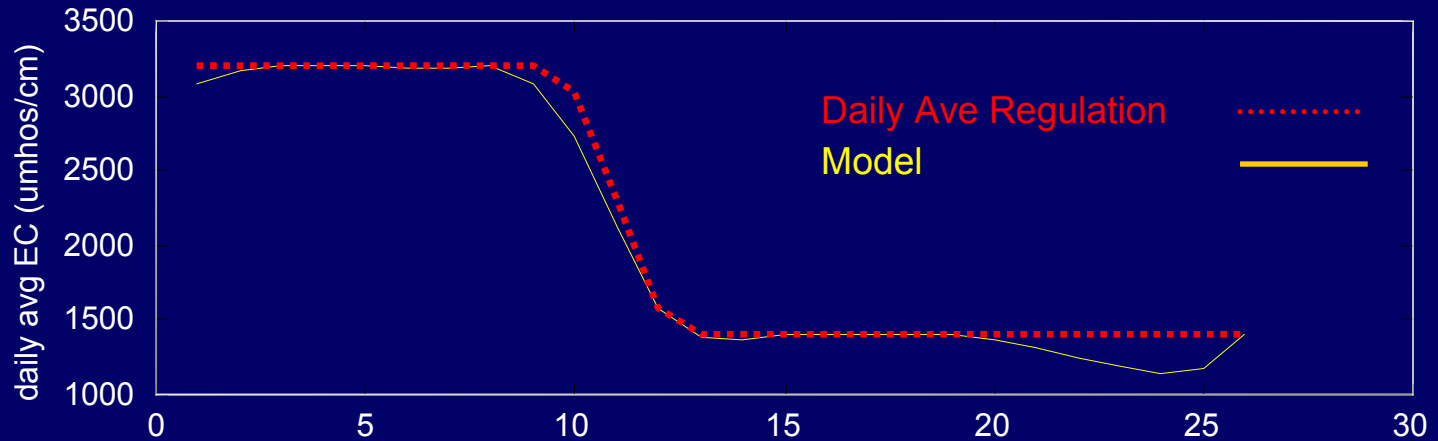
# CumulvsMxN Demo Shots

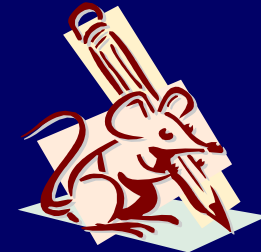
The image displays a screenshot of the AVS (Advanced Visual System) software interface. The main window, titled "AVS geometry viewer", shows a 3D visualization of a mesh structure, likely representing a terrain or a complex surface. The mesh is rendered in blue and black, showing a series of peaks and valleys. To the right of the main window, a "slicer" window is open, displaying a 2D heatmap of the data. The heatmap shows a color gradient from blue (low values) to red (high values), with a central region of high values (red) and a surrounding region of lower values (blue and green). The "slicer" window also includes a color scale bar ranging from -0.205208 to 0.205208. The AVS interface includes various control panels, including a "Data Viewers" panel on the left, a "Visualization Settings" panel, and a "Data Factory" panel at the bottom. The "Data Factory" panel shows a flowchart of data processing steps, including "Data Factory", "Time Stamp", "VizProxyText", and "CumulvsVizProxy".

# Adjoint Models and Sensitivity

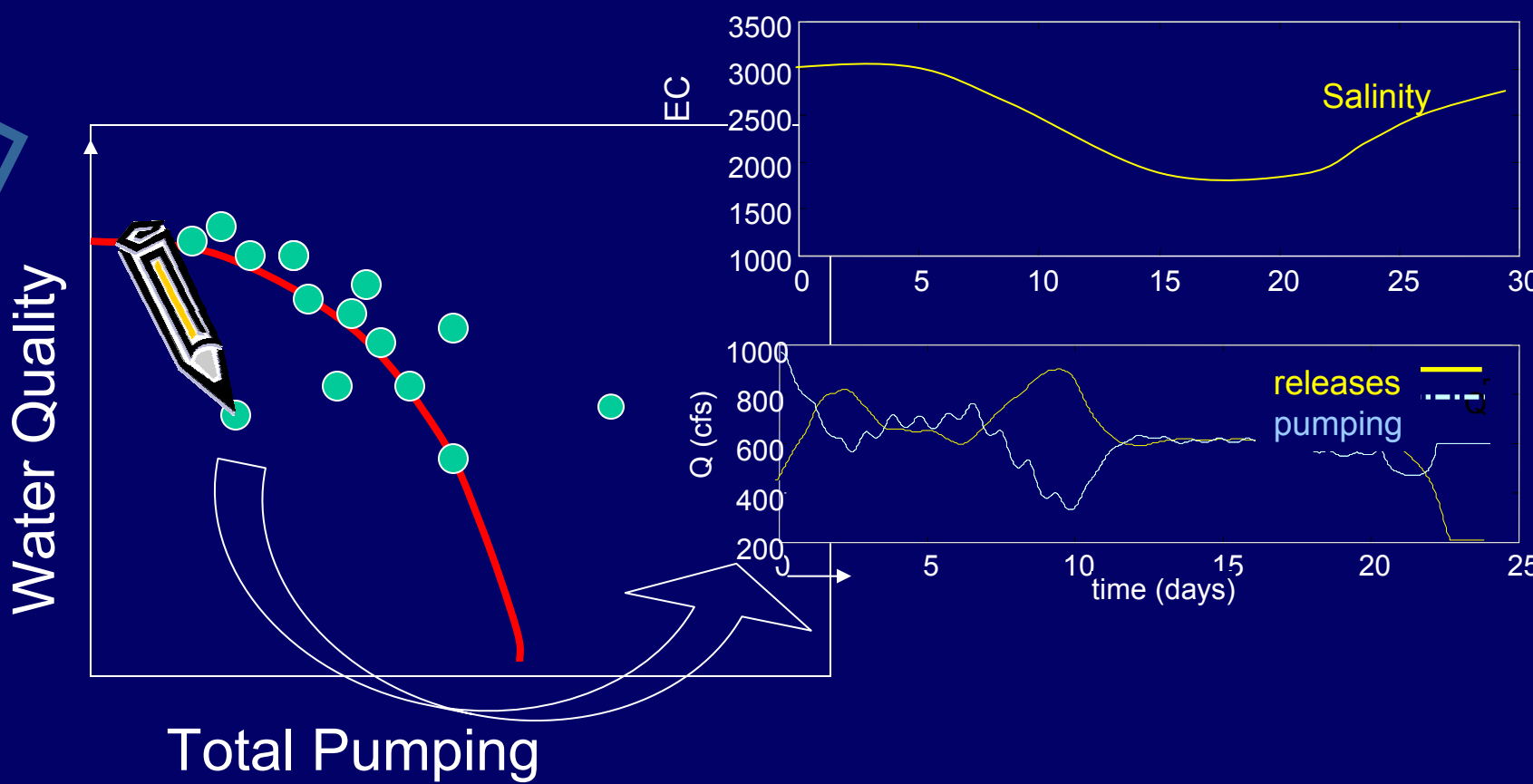


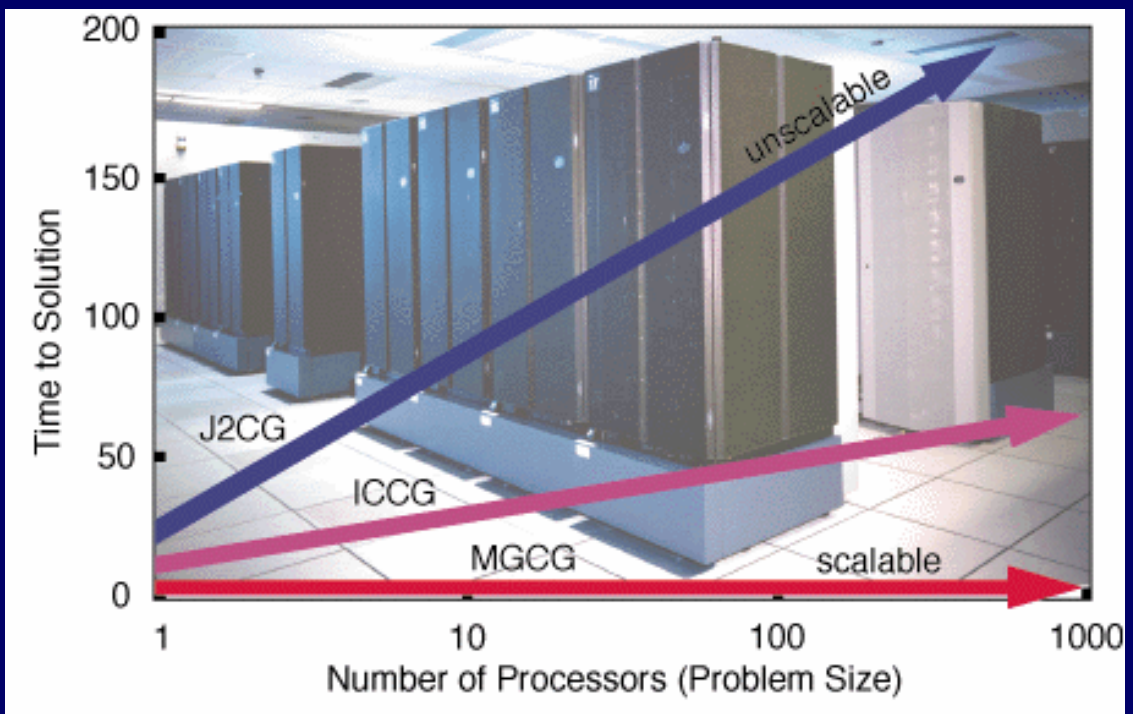
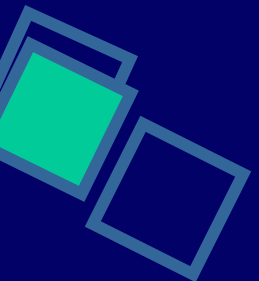
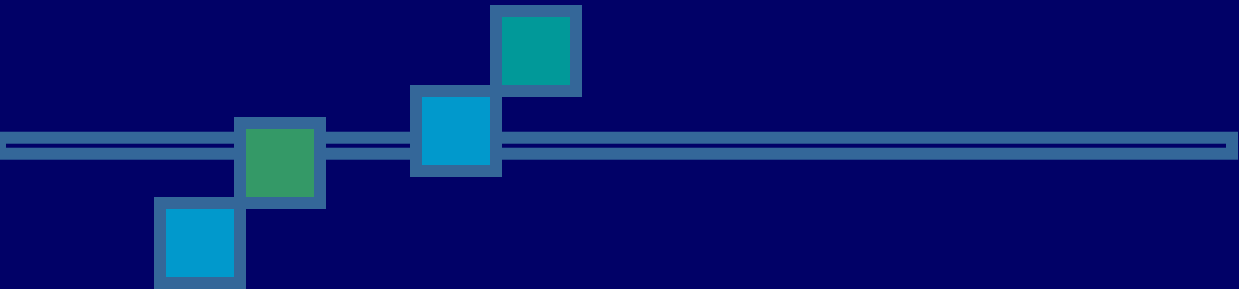
# Water Cost: Single Objective





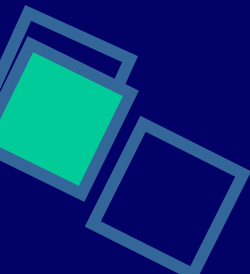
# Water Cost: Exploring Tradeoffs





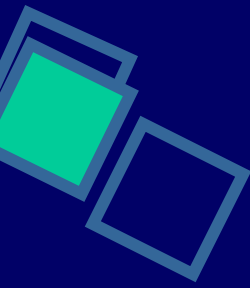


# REALM Phase I (12-18 months)

- 
- 2D model estuary hydrodynamic and water quality model
  - GIS front end for input and mesh development
  - Visualization hookup to output storage format (HDF5)
  - Mathematical hooks for optimization and data assimilation

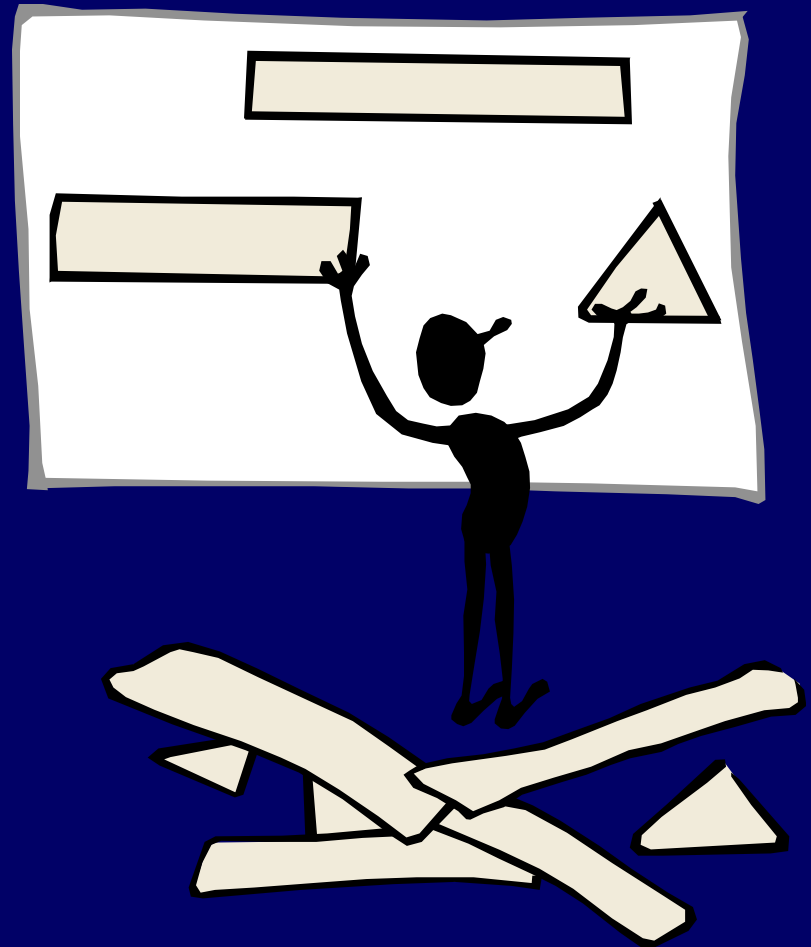


# REALM Phase II (12-18 months)

- 
- Adaptive 3D calculation of stratified flow and special study areas
  - Adaptive particle modeling
  - Prototype data assimilation
  - Performance and usability enhancements
  - Emphasize design cycle based on users

# Where Are We?

- Conceptual design finished
- Major tasks and leadpersons identified





# Where Are We?

- Contracts being developed:
  - LBL work
  - GIS work
  - Contract programmer



# *REALM*

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