Overview of TM6: Simulation of Selenium Fate and Transport in North San Francisco Bay

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Presentation to
TMDL Advisory Committee
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Overview

- Goal: Develop tool to calculate selenium in water and biota in response to different loads of selenium entering North San Francisco Bay
  - Technical Review Process
  - Modeling Approach
  - Selenium Loads
  - Example Calibration Results
  - Predicted Loads and Concentrations
  - Role of Boundary Conditions
  - Model Scenarios

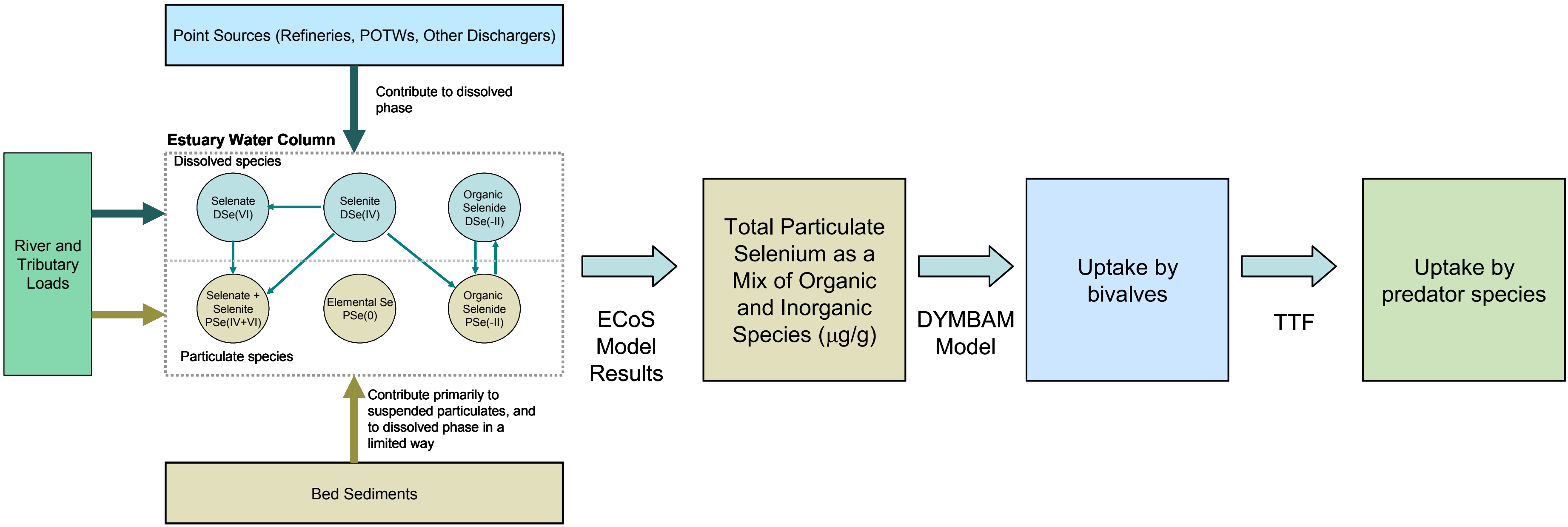
Technical Review Committee (2007-2010)

- Dr. Nicholas S. Fisher, State University of New York, Stony Brook
- Dr. Regina G. Linville, California State Office of Environmental Health Hazard Assessment
- Dr. Samuel N. Luoma, Emeritus, U.S. Geological Survey
- Dr. John J. Oram, San Francisco Estuary Institute

The role of the Technical Review Committee was to provide expert reviews of the modeling process as well as credible technical advice on specific issues arising during the review.

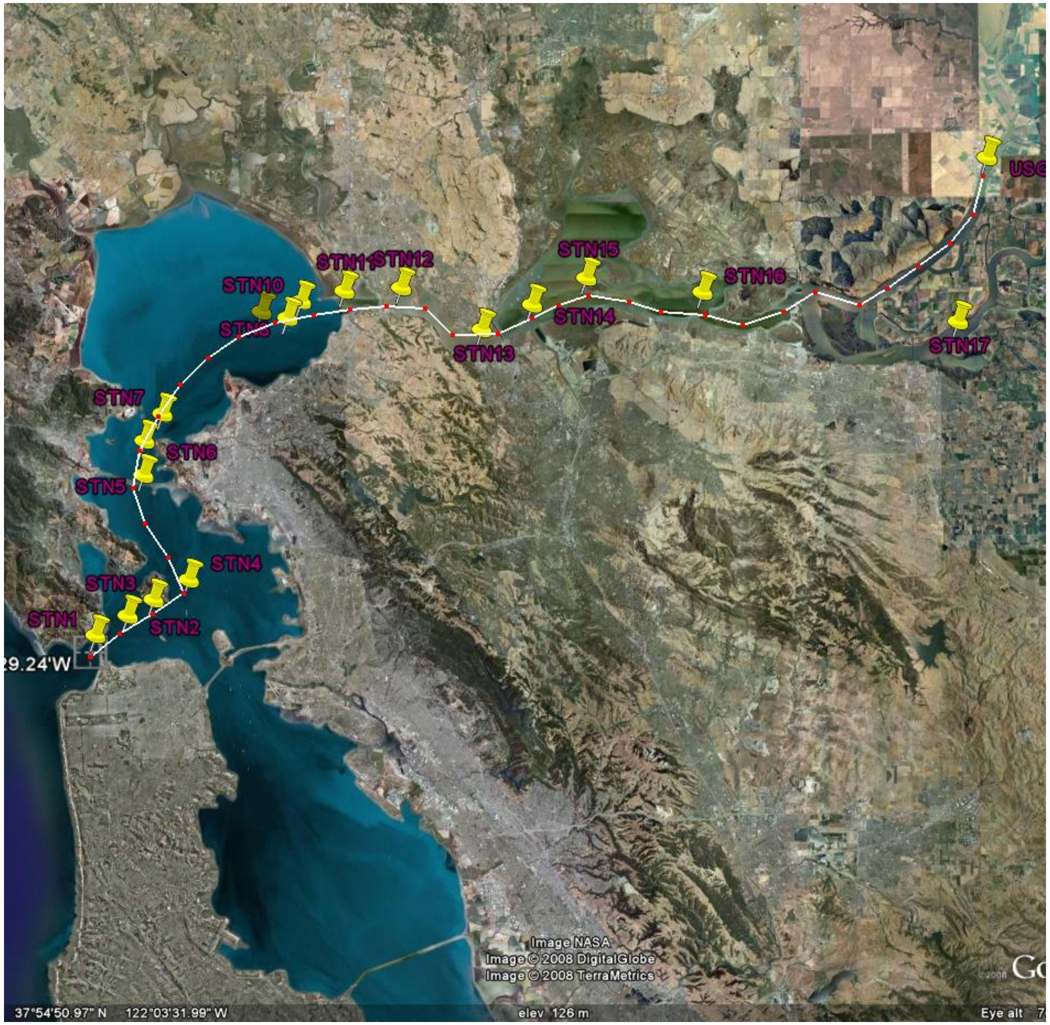
Final TM-6 report includes their comments and our responses.

Model Structure



ECoS = Fate and transport modeling framework for selenium species
DYMBAM = Dynamic Bioaccumulation Model for estimating bivalve concentrations
TTF = Trophic Transfer Factor, ratio between food and predator tissue concentration

Study Domain



Red dots: approximate locations of model segments

Yellow pins: sampling stations in Cutter and Cutter (2004) survey

Model domain starts at Sacramento River at Rio Vista and extends to Golden Gate

Model Components and Steps in Calibration

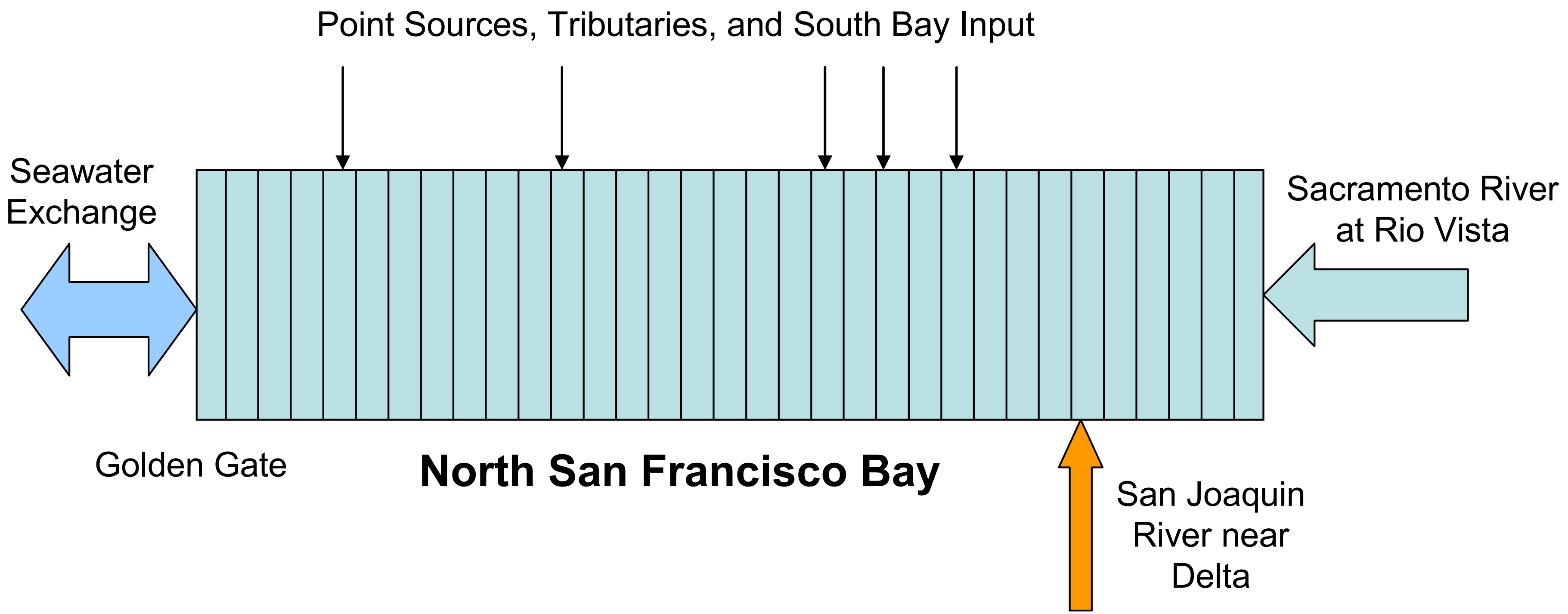
1. **Salinity:** relatively conservative (advection and dispersion)
2. **Total Suspended Material**: three components of PSP, BEPS and phytoplankton, result of advection, dispersion
3. **Phytoplankton (Chl a)**: result of advection, dispersion, growth, respiration, and grazing
4. **Dissolved selenium**: selenite (SeIV), organic selenide (SeII), selenate (SeVI)
5. **Particulate selenium**: particulate elemental , particulate organic selenide , particulate adsorbed selenite + selenate

Transformation modeled as first order reactions; transformations include: uptake by phytoplankton, adsorption/desorption, oxidation, mineralization

Modeling Steps

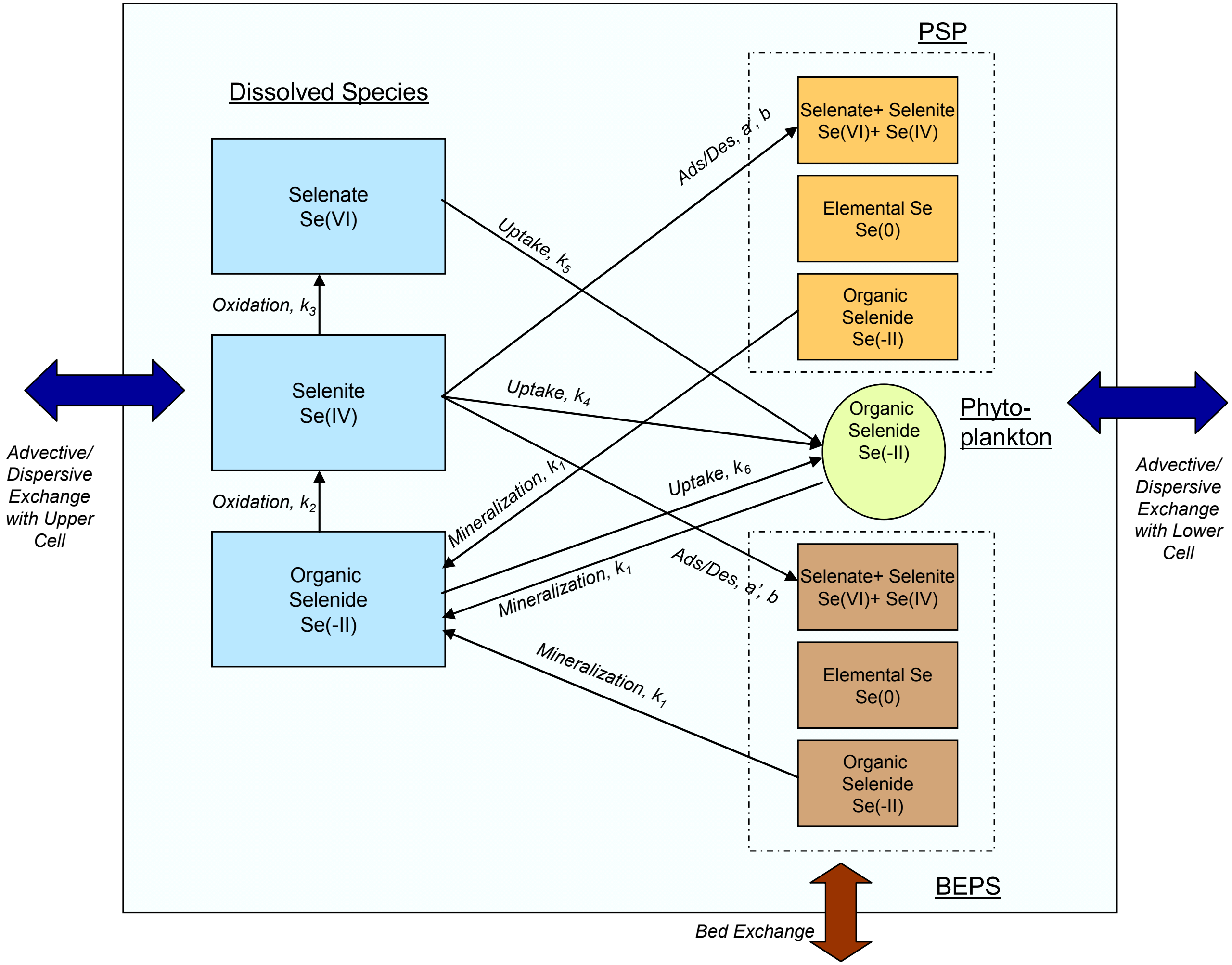
- During model calibration, adjustable parameters were varied to obtain a best fit to the data; for evaluation, the model was run with the fitted parameters and compared with new data sets
- Model calibrated to data from 1999, and tested against datasets from 2001, 2005, 1998 and 1986
- Model applied in a predictive mode using historical hydrology and different load scenarios
- Tetra Tech worked with model developers (Shannon Meseck, John Harris) over the course of this work

Model Schematic



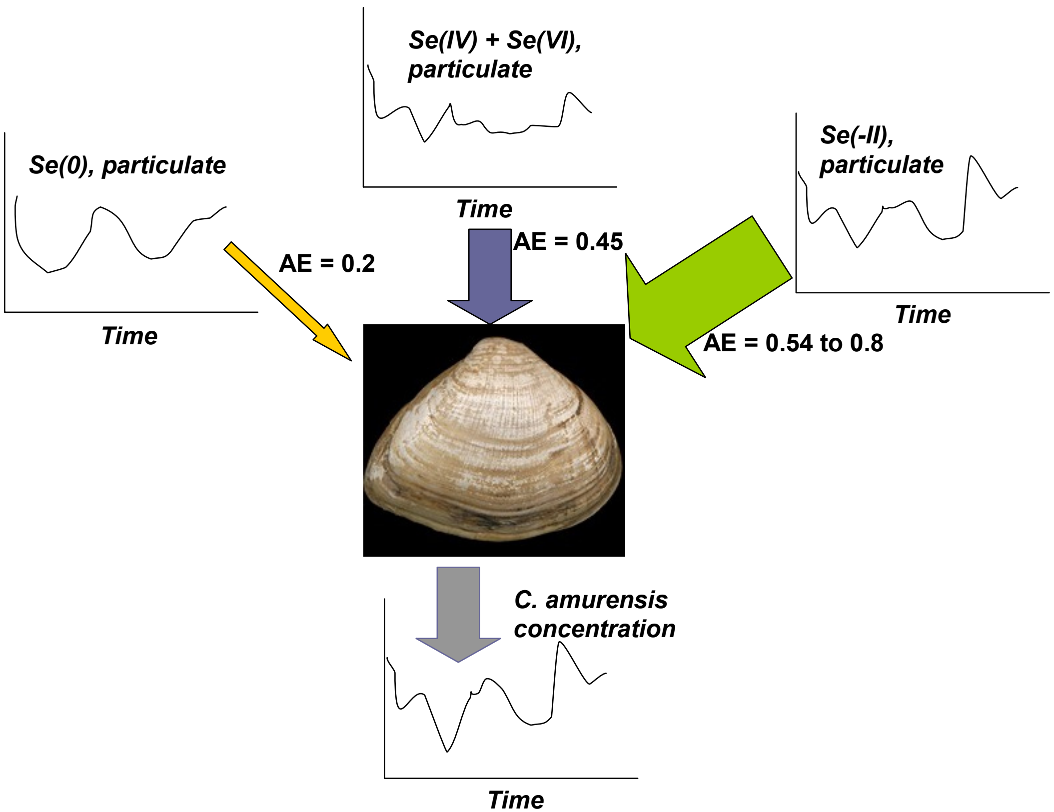
1-D model with 33 well-mixed cells representing the bay.

Selenium Transformations



Represented by first-order rate constants.

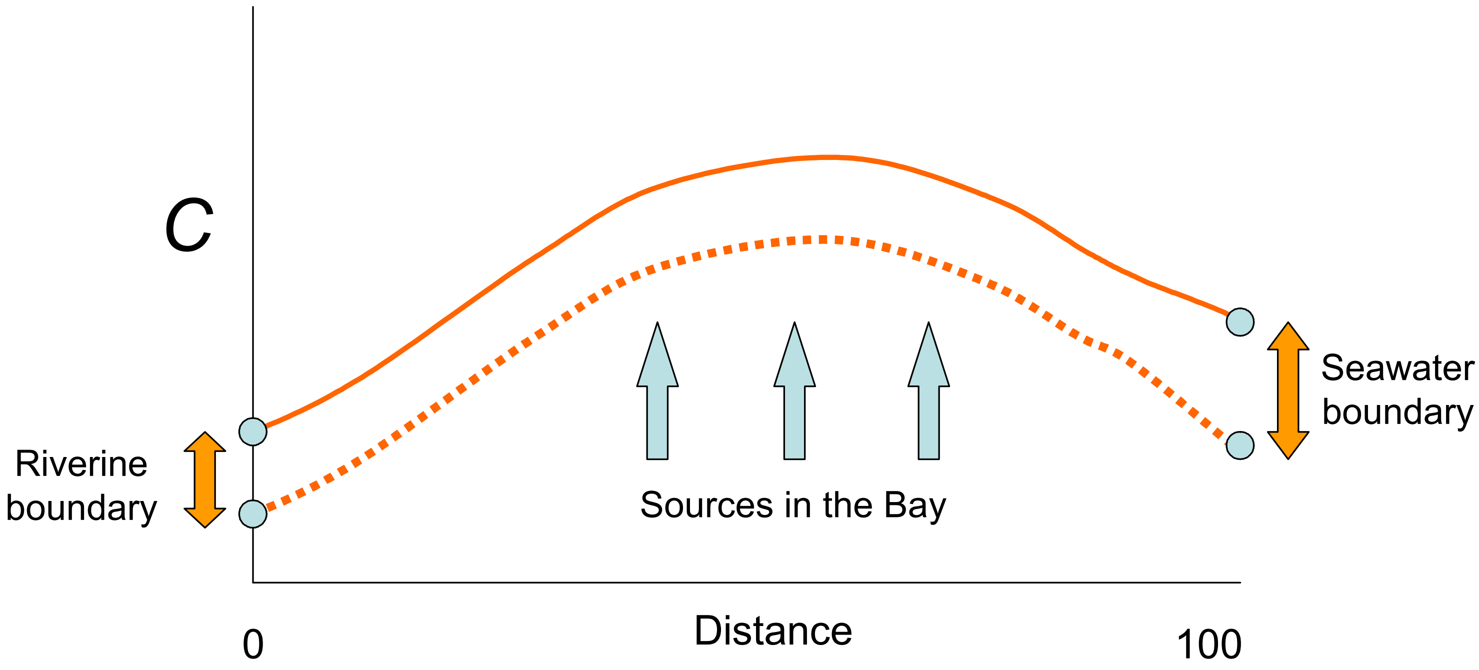
Uptake by Bivalves



$$dCmss/dt = ku \times Cw + AE \times IR \times Cf - ke \times Cmss$$

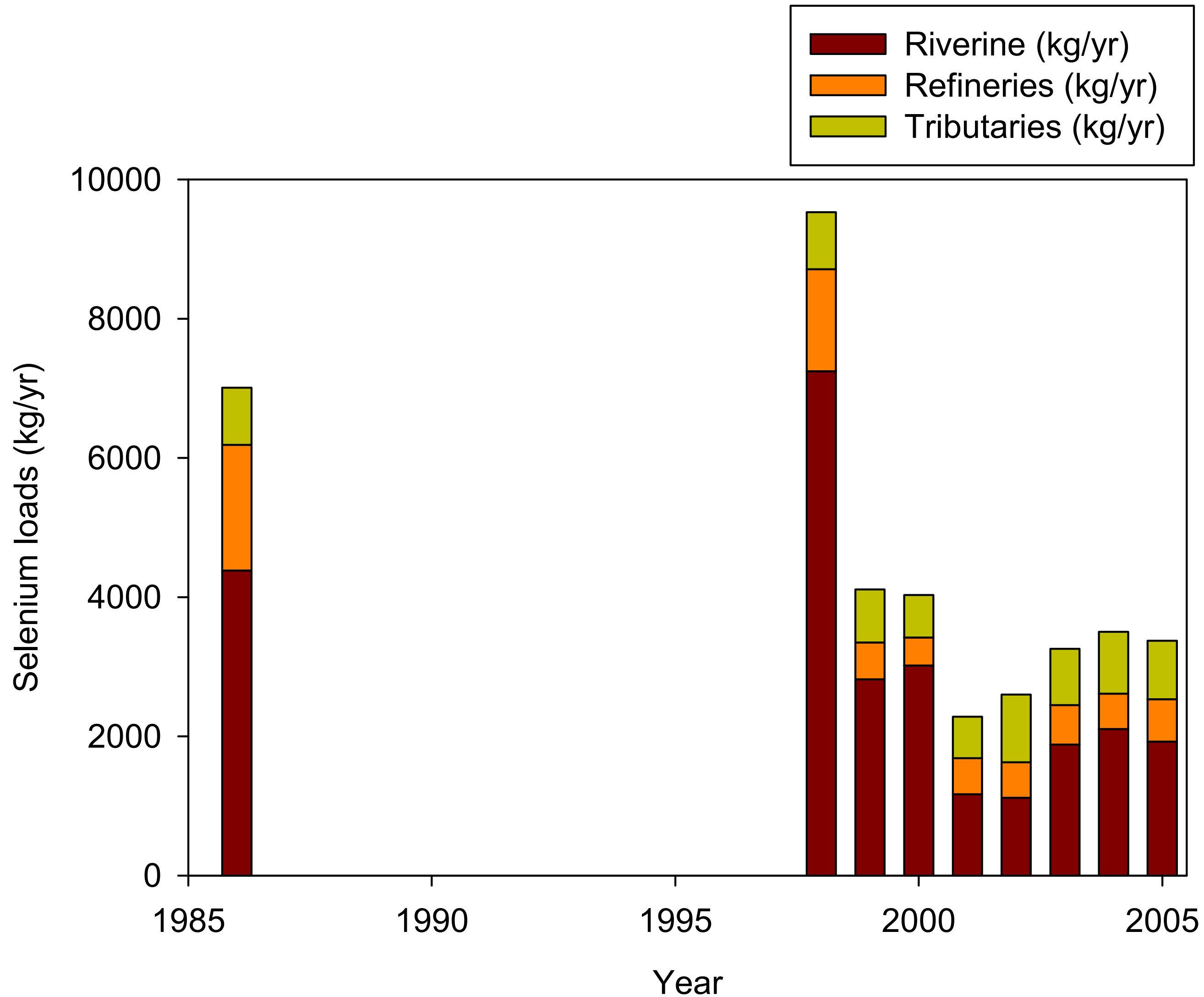
Cmss is selenium concentration in tissue (µg/g), ku is the dissolved metal uptake rate constant (L/g/d), Cw is the dissolved metal concentration (µg/L), AE is the assimilation efficiency (%), IR is the ingestion rate (g/g/d), Cf is the metal concentration in food (e.g. phytoplankton, suspended particulate matter, sediment) (µg/g), and ke is the efflux rate (d^{-1}).

Boundary Conditions are Important

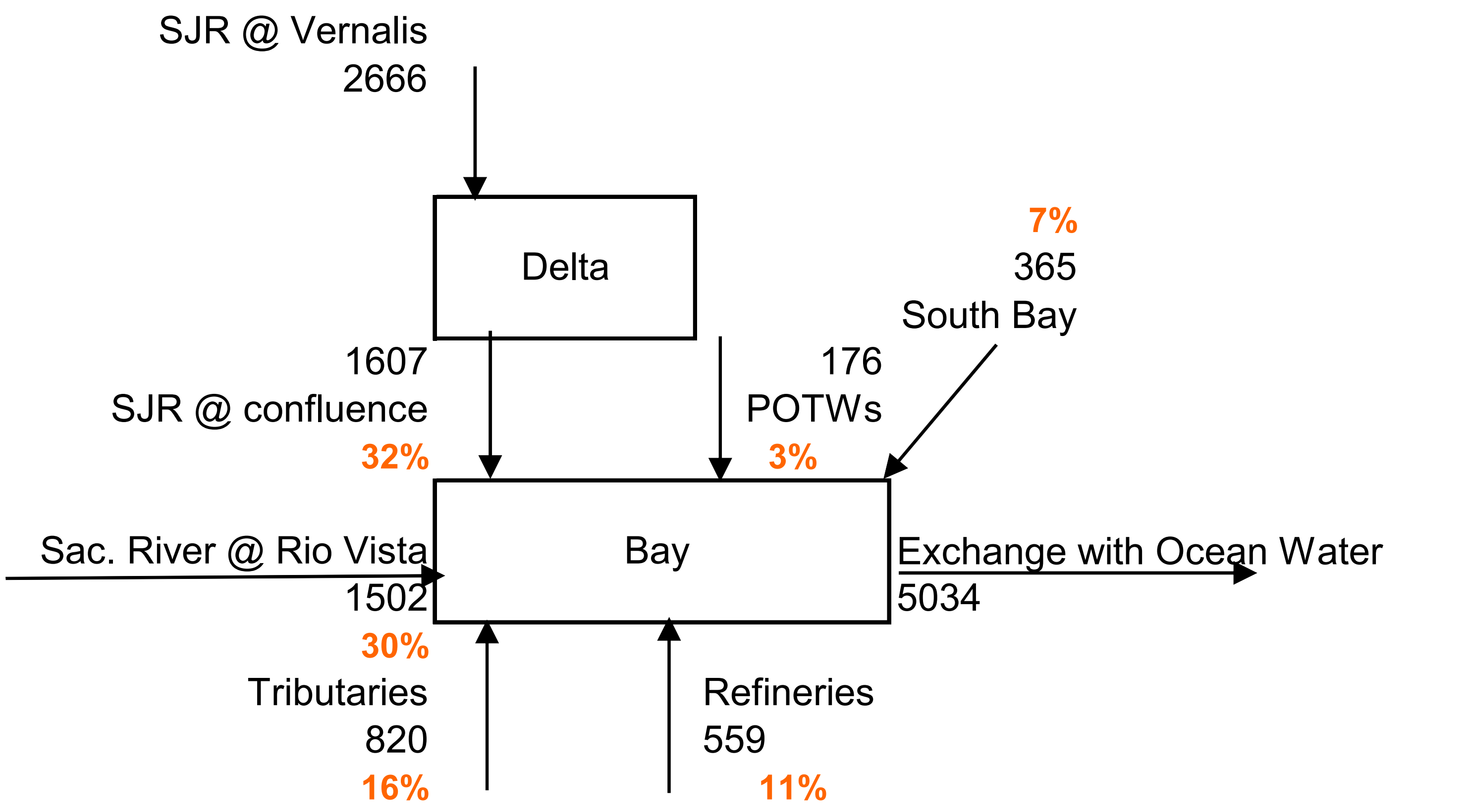


C, on the y-axis, represents a constituent being modeled. The model framework shown on the preceding slides involves the solution of a set of differential equations. These explain the shape of the curve. However, the boundary conditions also have an important effect on determining the actual magnitudes of C.

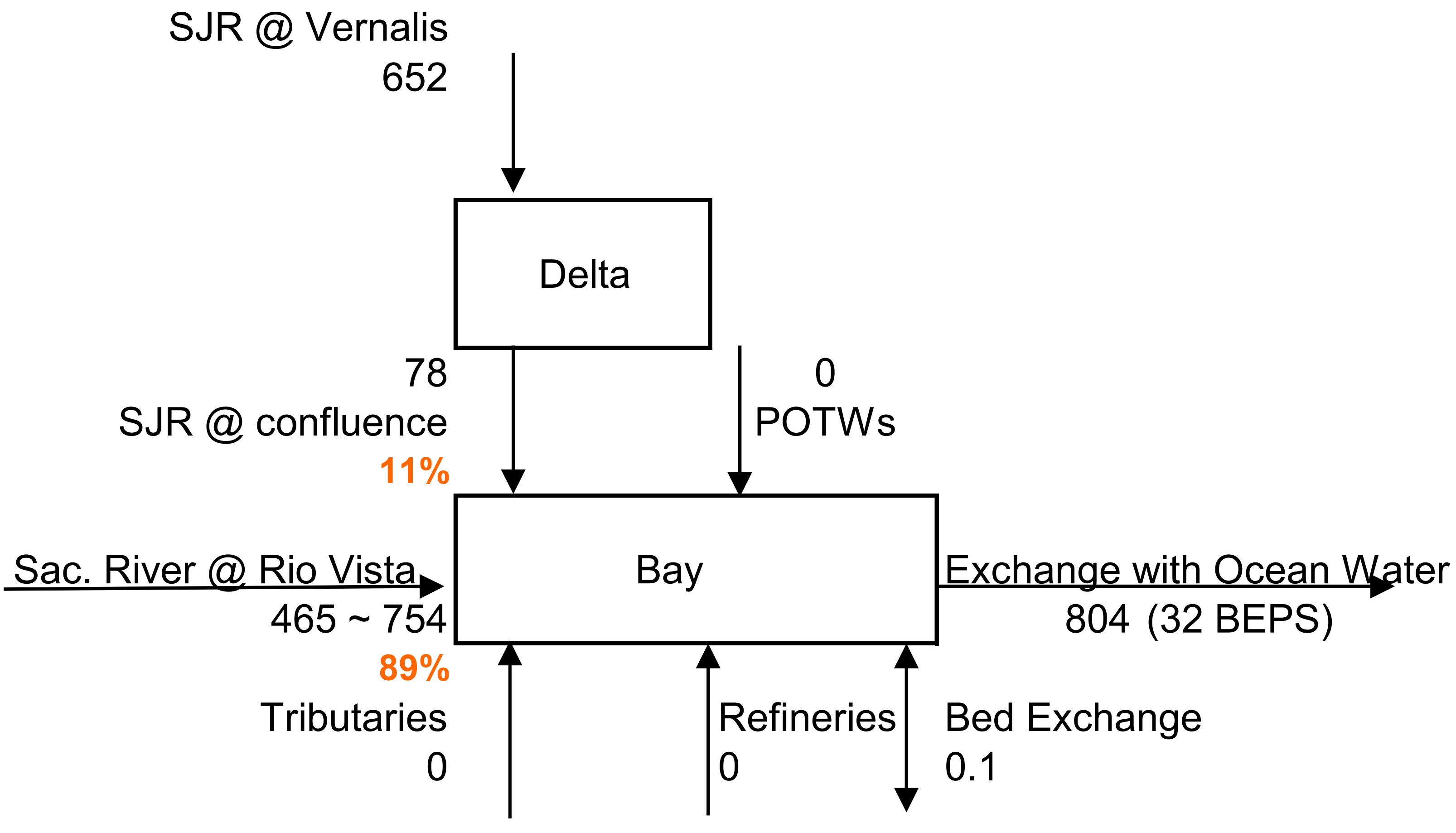
Annual Selenium Loads



Dissolved Loads for Water Year 1999

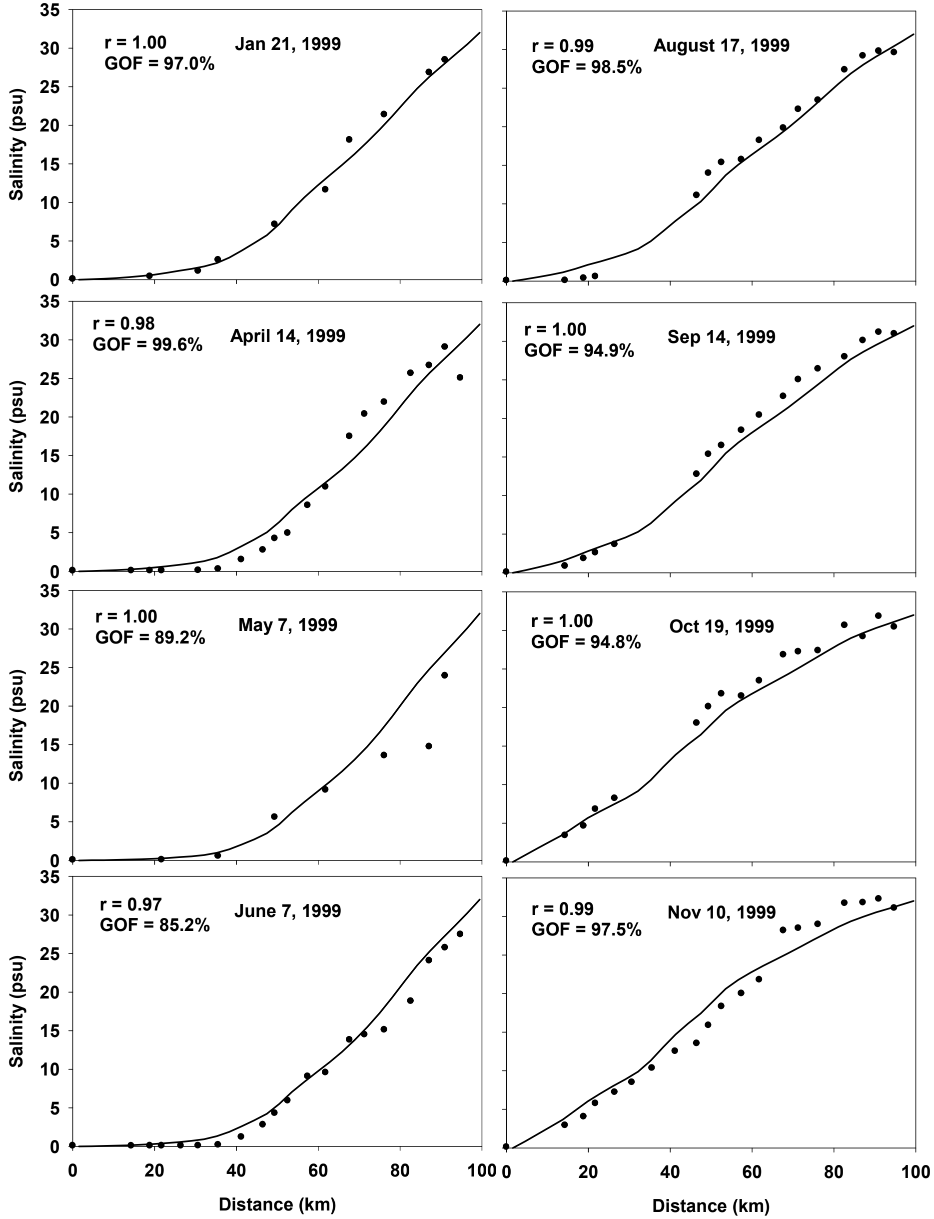


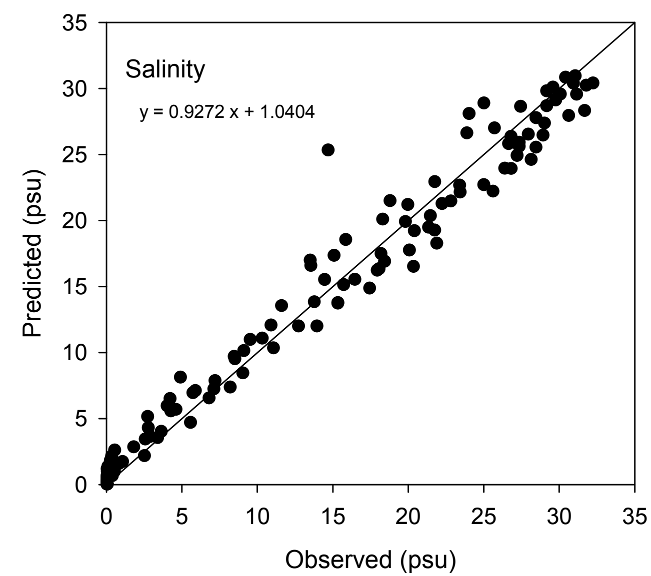
Particulate Loads for Water Year 1999



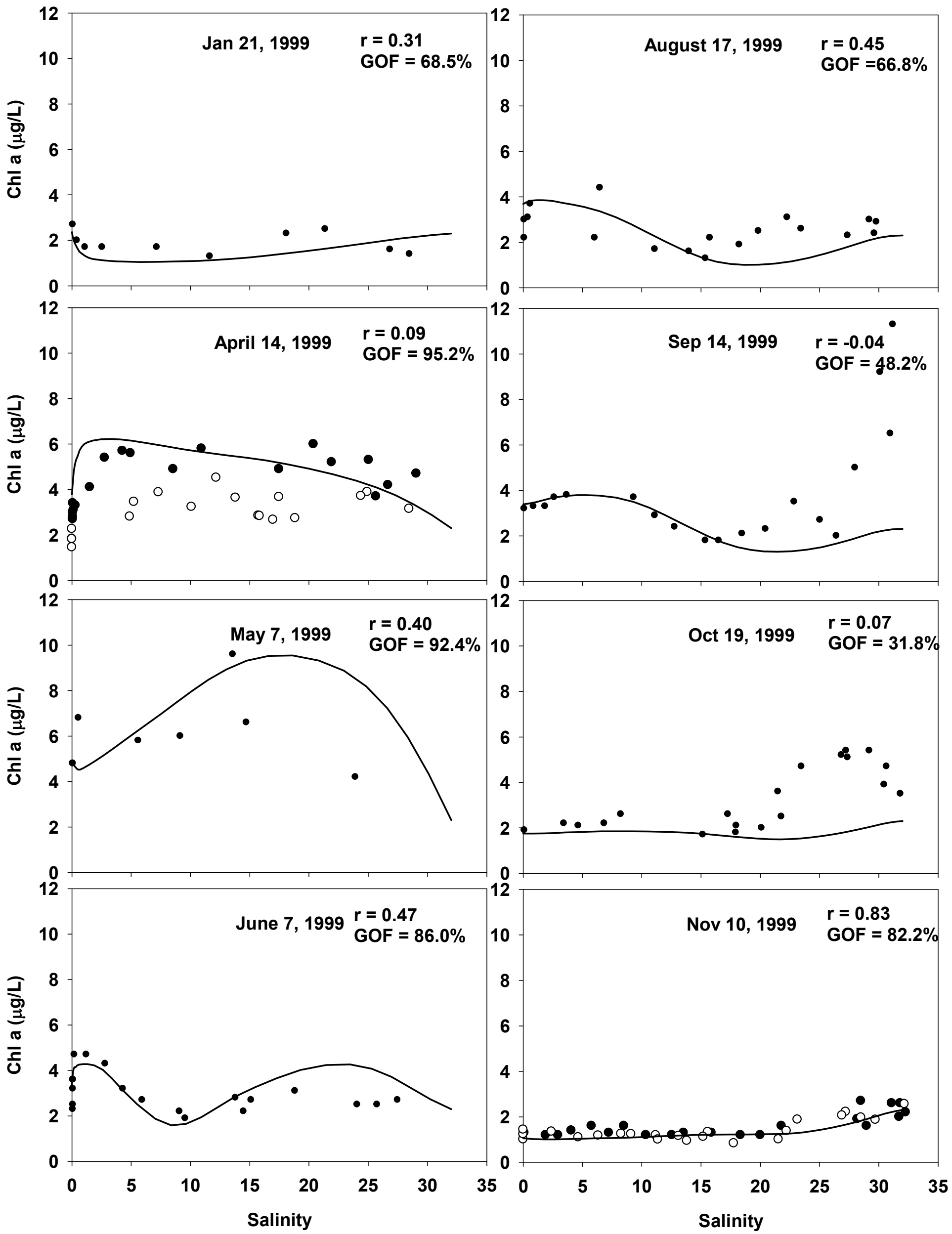
Example Calibration 1: Salinity (1999)

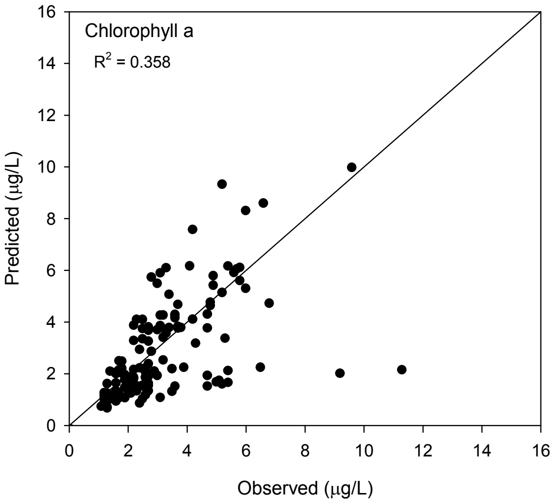
$$GOF\ (\%) = 100 * \left(1 - \left|\sqrt{\frac{\sum Xcal}{\sum Xobs}} - \sqrt{\frac{\sum Xobs}{\sum Xcal}}\right|\right)$$



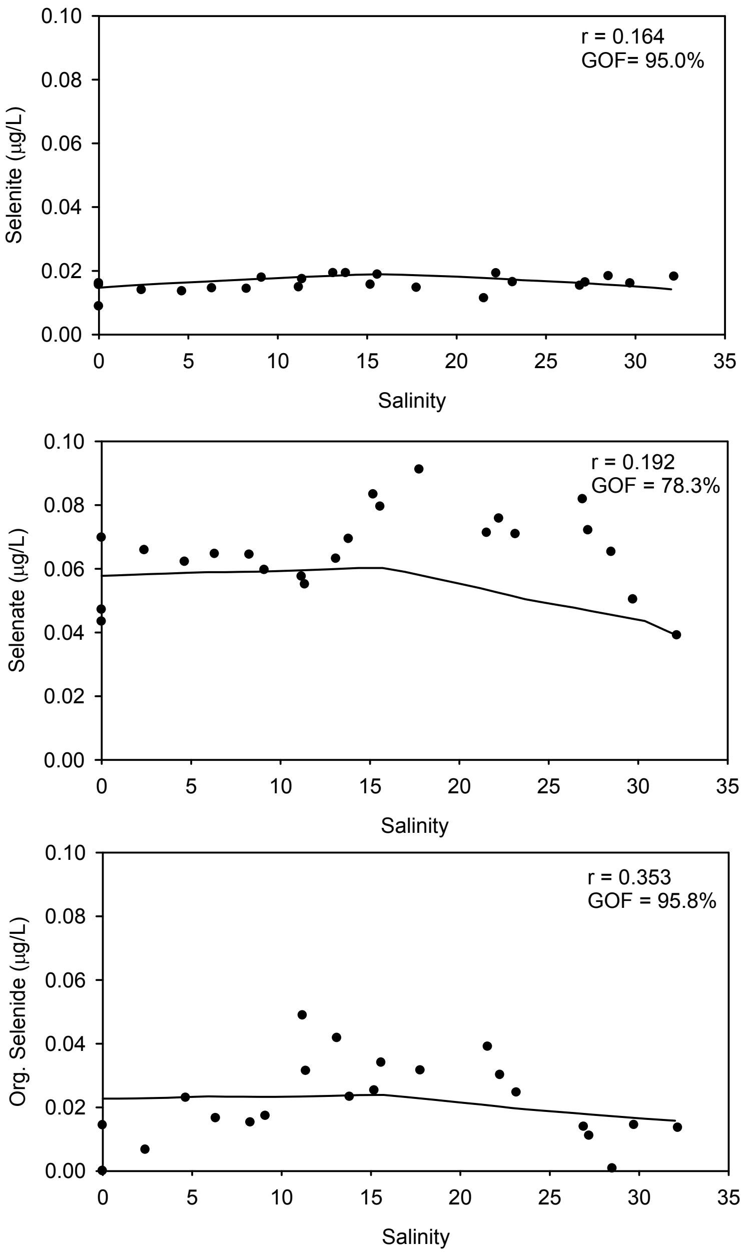


Example Calibration 2: Chlorophyll a (1999)

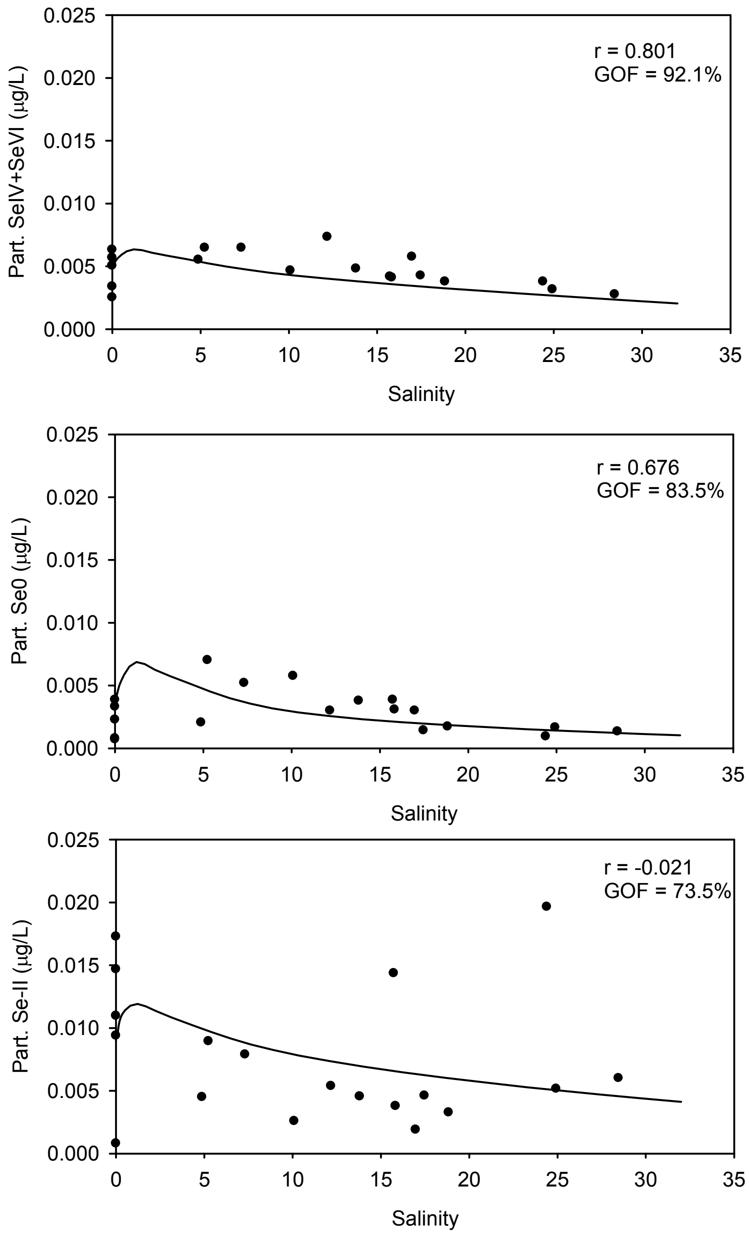




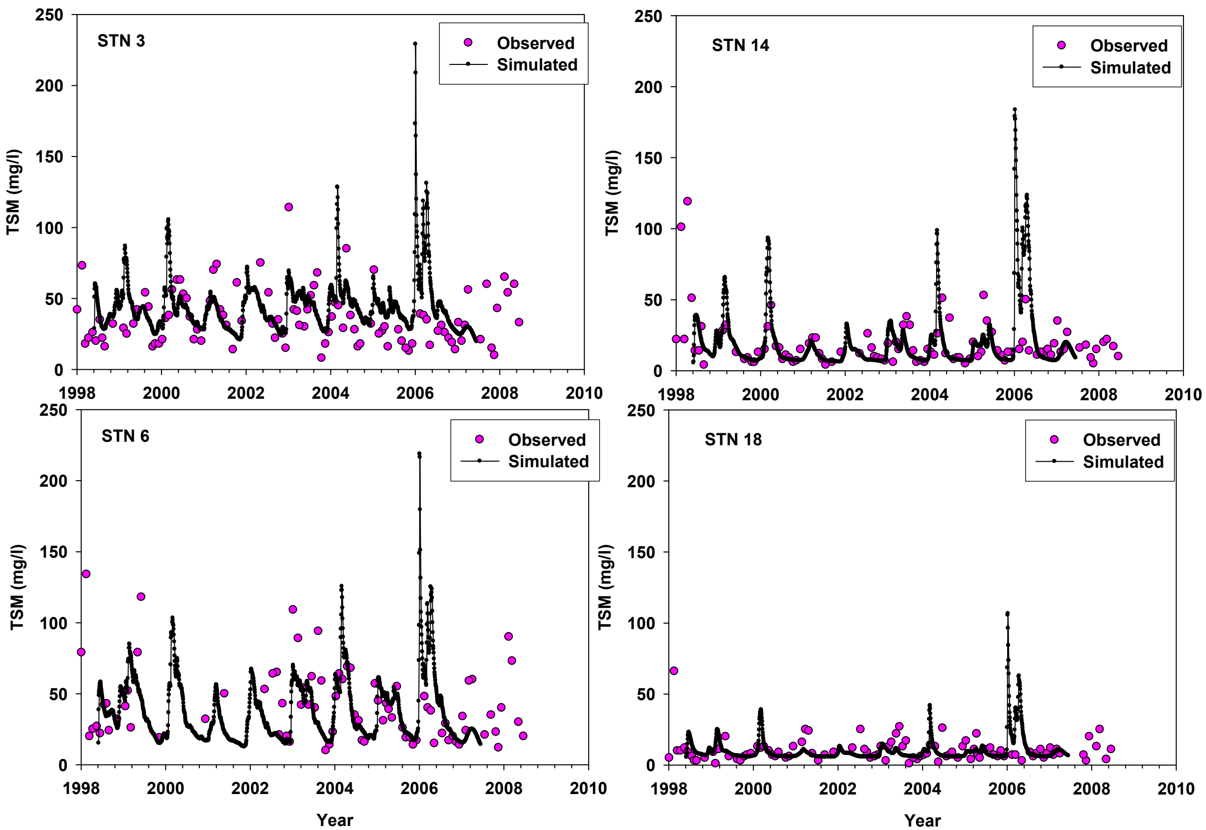
Example Calibration 3: Dissolved Selenium (1999)



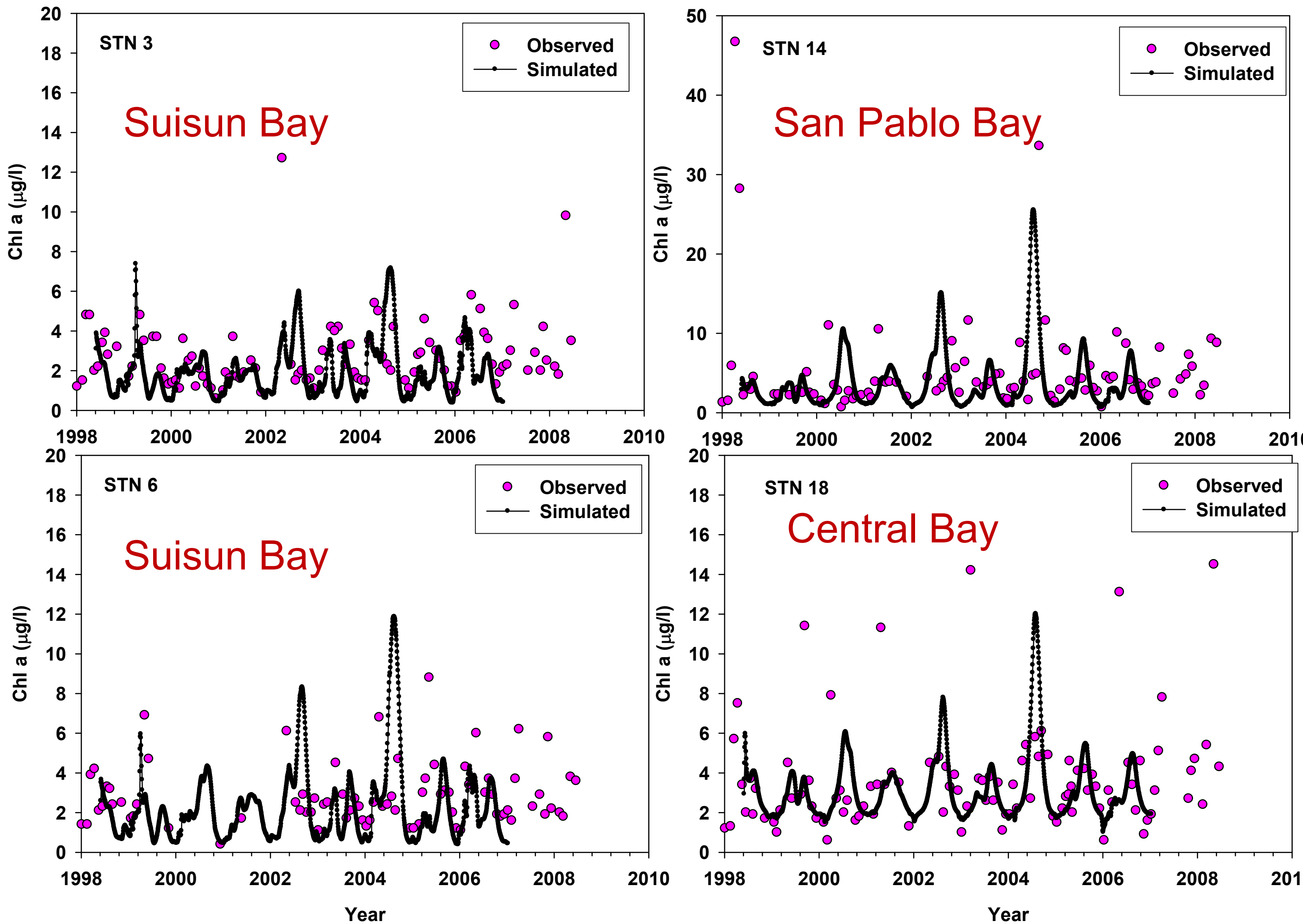
Example Calibration 4: Particulate Selenium (1999)



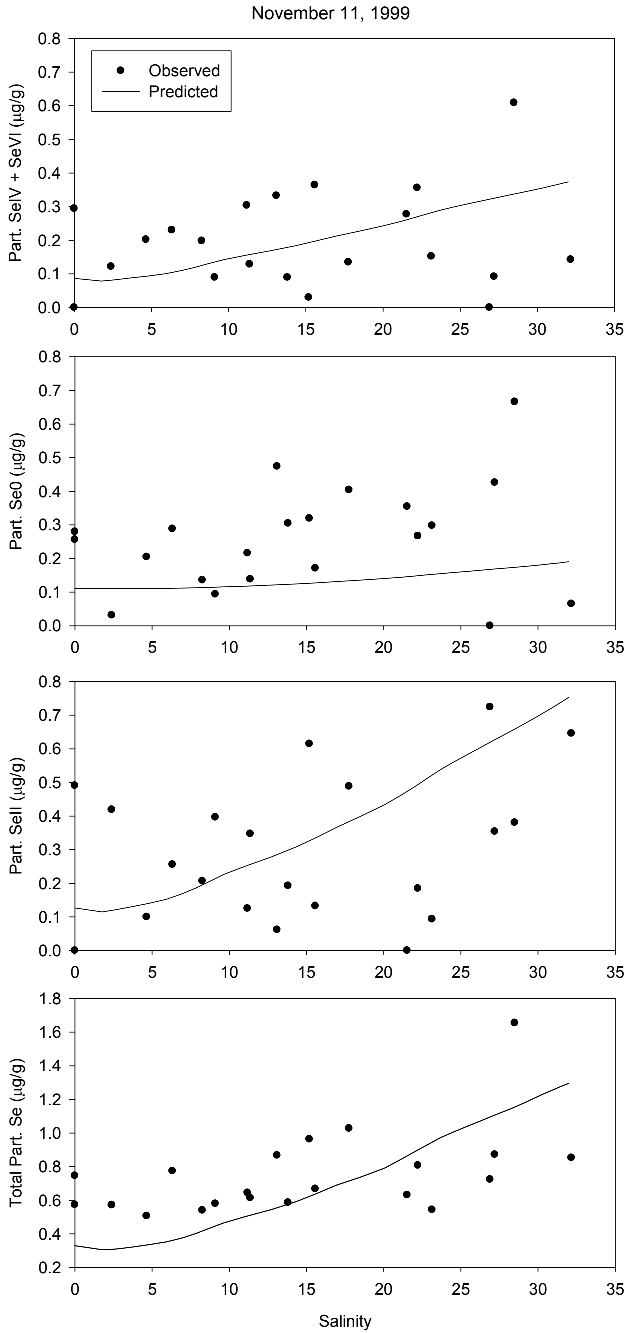
TSM Long-Term Evaluation at USGS Stations



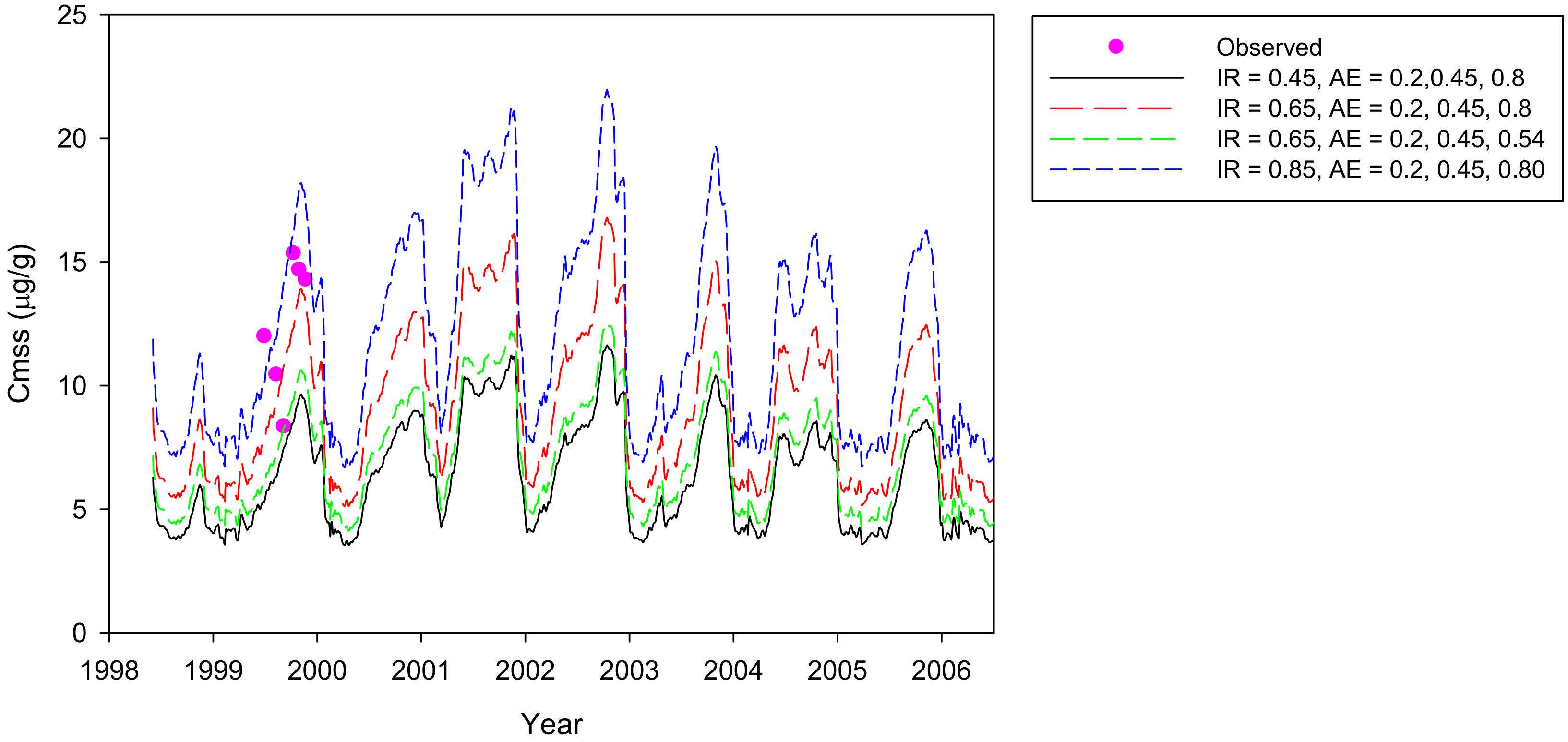
Evaluation of Chlorophyll a



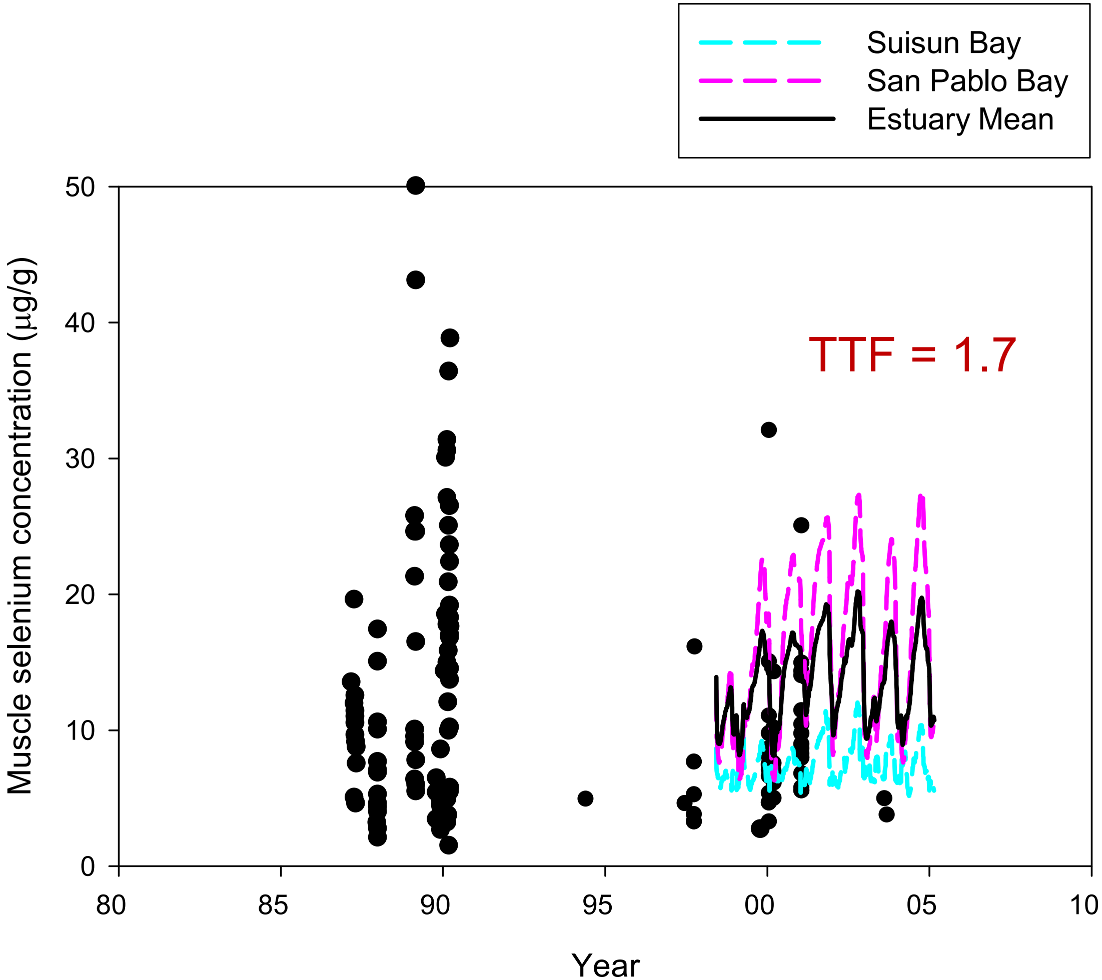
Predicted Particulate Selenium Concentrations (1999)



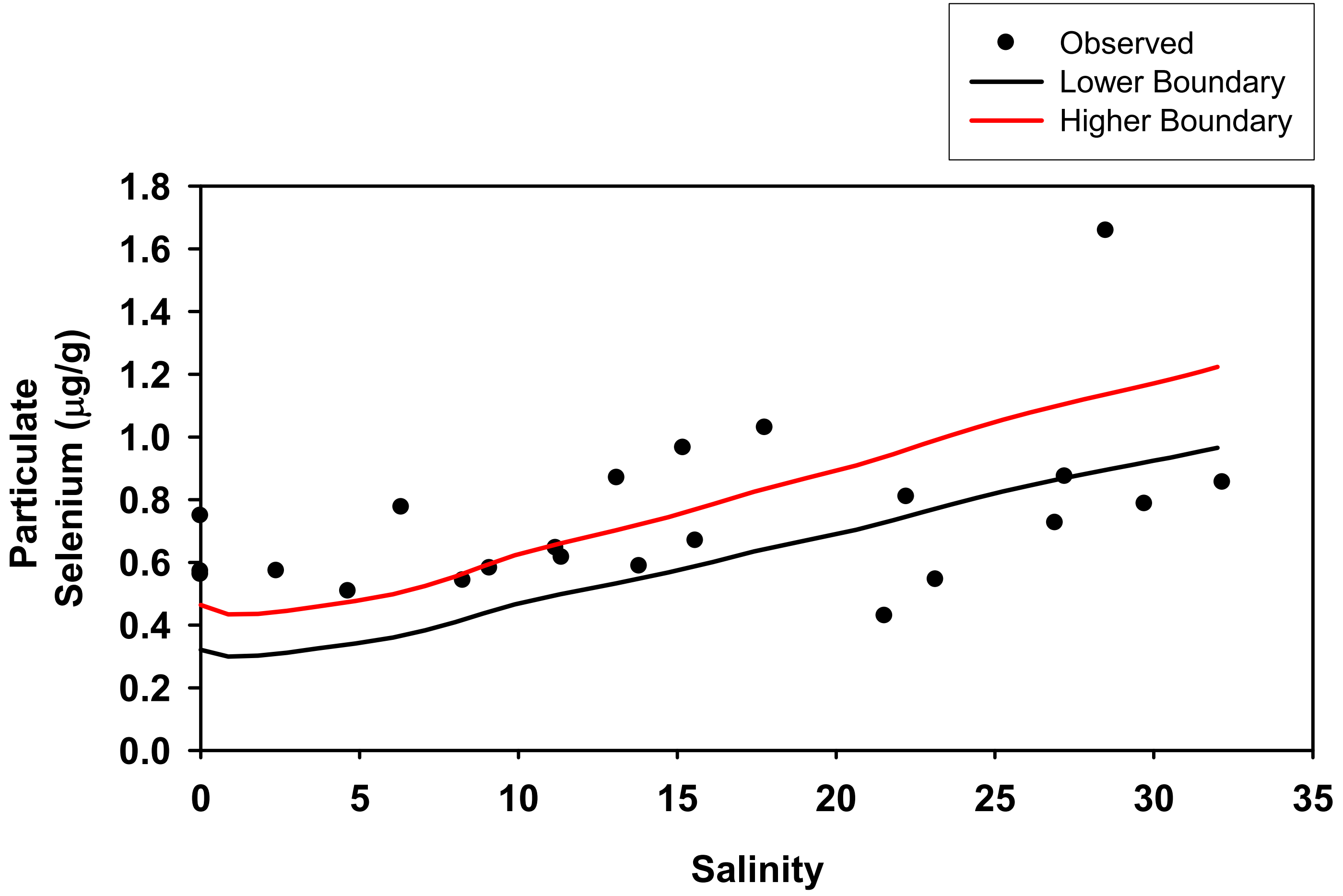
Bivalve (*C. amurensis*) Concentrations



White Sturgeon Concentrations



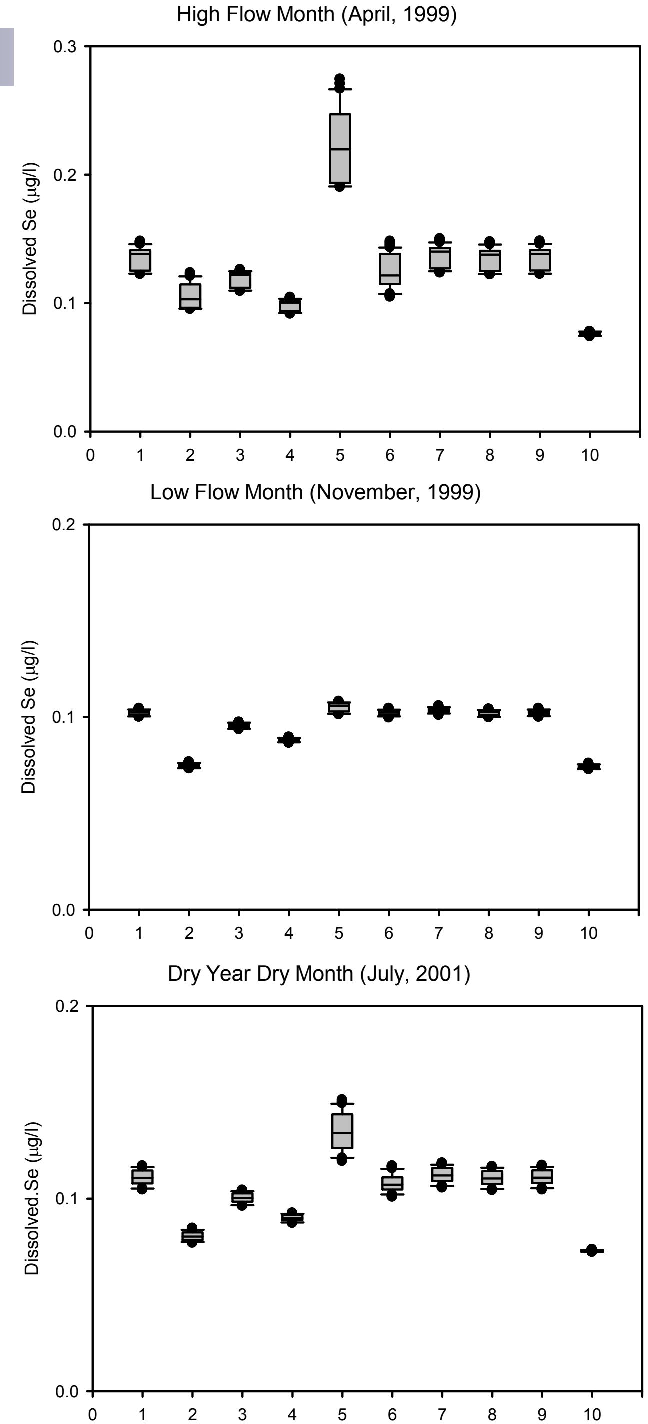
Effect of Changing Boundary Conditions



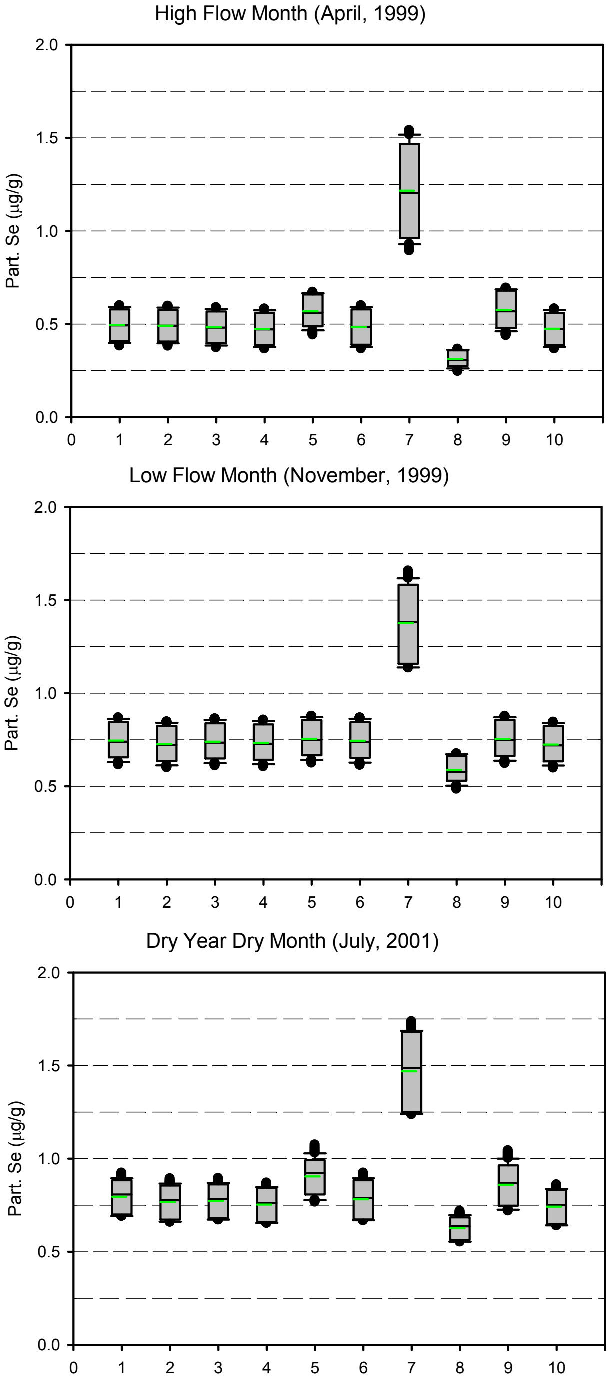
Scenarios Examined

Scenario	Description
1	Base case
2	Removal of all point source loads (refineries, POTWs), and local tributary loads
3	30% reduction in refinery and San Joaquin River loads, dissolved only
4	50% reduction in all point sources (refineries, POTWs), local tributaries and San Joaquin River loads, dissolved only
5	Increase dissolved selenium loads from San Joaquin River by a factor of 3, particulate loads remain the same as the base case
6	Decrease dissolved selenium loads from San Joaquin River by a factor of 50%, particulate loads remain the same as the base case
7	Increase particulate selenium loads associated with PSP, BEPS, and phytoplankton from Sacramento River by a factor of 3, dissolved loads remain the same as the base case
8	Decrease particulate selenium loads associated with PSP, BEPS, and phytoplankton from Sacramento River by a factor of 50%, dissolved loads remain the same as the base case
9	Increase San Joaquin River particulate loads by 3x, other loads stay the same
10	A natural load scenario, where the point sources are zero, the local tributary loads and speciation are at Sacramento River values, and the San Joaquin River is at 0.2 µg/l, at current speciation

Impact on Dissolved Se



Impact on Particulate Se



Summary of Model Results

- The model is able to simulate key aspects of physical and biological constituents that affect selenium concentrations.
- During calibration, the model was able to fit the patterns in concentrations of dissolved and particulate selenate and selenite well, although it performed less well for the organic fractions. The model was also able to represent the observed variation in biota concentrations.
- The model is a valuable tool to explore selenium transport, fate, and bioaccumulation in the bay, and can be applied in analyses in support of the TMDL, as demonstrated through a set of example scenarios.
- A modeling study provides an opportunity to synthesize information from the system, and in doing so, highlights unknowns that may have a bearing on model predictions.
- This report presents a set of data needs for further evaluation such as characterization of boundary conditions, selenium loads from major sources, recent water column concentrations and speciation, as well as biota concentrations.

Impact on Bivalve Se