Modeling Selenium in North San Francisco Bay

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Abstract

This poster describes the application of a numerical model of selenium fate and transport in North San Francisco Bay (NSFB), in support of the development of a selenium TMDL in this water body (see Baginska et al., this conference). The model builds on a previously published application, and considers known point and non-point sources of selenium entering the bay, transport and mixing in the bay, and transformation and biological uptake. The model considers the behavior and uptake of different dissolved and particulate species. Dissolved species considered include selenate, selenite, and organic selenide. Particulate species considered include inorganic selenium (selenate plus selenite), organic selenide, and elemental selenium. Data on all these species is available for a set of sampling dates in the mid-1980s and late-1990s. The flows and selenium loads from the Sacramento and San Joaquin Rivers are dominant in the bay, although in the dry season, some of the point sources can become more important. Dissolved selenium concentrations (all species combined) in the NSFB are generally low (~0.2 ug/l). However, selenium present in particulate forms in the water column of the estuary bioaccumulates in filter feeders, such as bivalves, and then into predator organisms that feed on these bivalves. Selenium-associated impairment in NSFB is largely a consequence of elevated concentrations in these predator organisms, specifically the white sturgeon and diving ducks. The modeling framework allows an examination of the relationship between selenium loads, in-bay concentrations, and biota concentrations to support TMDL development.

1. Introduction

The San Francisco Bay Regional Board is developing a selenium Total Maximum Daily Load (TMDL) for North San Francisco Bay (NSFB), due to high concentrations in some organisms. In support of the NSFB selenium TMDL, an estuary model (developed using the ECoS 3 framework) was used to simulate the selenium concentrations in water column and bioaccumulation of selenium in the NSFB. The model built upon the previous work of Meseck and Cutter (2006).

The location of NSFB and the starting point of modeling domain (the "head" of the estuary) are shown in Figure 1. The end of the modeling domain is at Golden Gate Bridge.

Modeling Domain

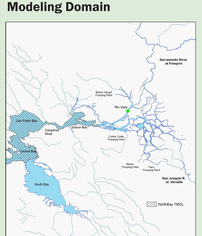


Figure 1. Boundaries of NSFB Selenium TMDL

2. Methods

The model was applied in one-dimensional form to simulate several constituents including salinity, total suspended material (TSM), phytoplankton, dissolved and particulate selenium and selenium concentrations in bivalves and higher trophic organisms (Figure 2).

The biogeochemistry of selenium, including transformations among different species of dissolved and particulate selenium and bioaccumulation of selenium through foodweb, was simulated by the model. Species simulated by the model include selenite, selenate, and organic selenide. The particulate species simulated by the model include particulate organic selenium, particulate elemental selenium, and particulate adsorbed selenite and selenate (Figure 3; Table 1). The uptake of dissolved selenium by phytoplankton includes uptake of three species (selenite, organic selenide and selenate). Bioaccumulation of particulate selenium to the bivalves was simulated using a dynamic bioaccumulation model (DYMBAM, Presser and Luoma, 2006), applied in a steady state mode. Bioaccumulation into bivalves considers the different efficiency of absorption for different selenium species (Figure 4). Bioaccumulation to higher trophic levels of fish and diving ducks was simulated using previously derived linear regression equations by Presser and Luoma (2006), and using estimates of trophic transfer factors (TTF) summarized from the literature (Presser and Luoma, personal communication, 2009).

The model was calibrated using data from 1999 and validated against data for the rest of the simulation period (2000-2008)

Model Components

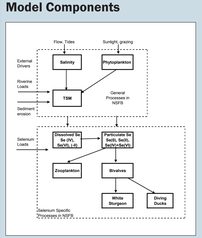


Figure 2. Model Components of ECoS3 Application in NSFB

Selenium Transformations Simulated

Transformations among dissolved selenium species are used to slow processes.

Particulate selenium can be associated with Permanently Suspended Particulates (PSP), phytoplankton, and Bed Exchangeable Particles (BEPS).

The uptake of dissolved selenium by phytoplankton depends species (greater in selenite and organic selenide than selenate).

Figure 3. Transformations of dissolved and particulate selenium

Table 1.
Literature values for first order rate constants

Constant	Process	Description	Value	Unit	Reference
k_1	P Sec (I) → D Se (I)	Dissolution of particulate selenite	$2.3e-10*2.e+13^T$	s^{-1}	Bioparameters experiments (Cutter, 1992)
k_2	D Sec (I) → D Se (O)	Oxidation of dissolved organic selenide	$1.0e+12^T - 81.0$	s^{-1}	Surface and deep Pacific Ocean (Cutter and Cutter, 1995); Ulatt in Cutter, 1992)
k_3	D SeO3 → D Se (O)	Oxidation of dissolved selenite	$2.e+10^T$	s^{-1}	Deep Pacific, Cutter and Bruland (1984)
k_4	D SeO3 → P Se (A)	Uptake of dissolved selenite by phytoplankton	$2.02.0.41$ (15.8-18.8)	$\mu mol\ Se\ (\mu g\ chl)^{-1}hr^{-1}$	Riedel et al. (1996)
k_5	D SeO4 → P Se (A)	Uptake of dissolved selenate by phytoplankton	$0.01.0.21^{-1}$ (228.5-717.8)	$\mu mol\ Se\ (\mu g\ chl)^{-1}hr^{-1}$ (5g chl a/m)	Baines et al. (2004)
k_6	D Se(-II) → P Se (A)	Uptake of dissolved organic selenide by phytoplankton	0.43-0.58	$\mu mol\ (g\ chl)^{-1}hr^{-1}$	Riedel et al. (1996)
k_7	D Se(-II) → P Se (A)	Uptake of dissolved organic selenide by phytoplankton	0.5 k_6	$\mu mol\ (g\ chl)^{-1}hr^{-1}$	Baines et al. (2001)
d	P SeO4 → Fine (O)	Mineral precipitation of selenite	0.1-0.8	mg/d	Zhang and Sparks (1993)
k_8	P Se(+) → D SeO3	Oxidation of adsorbed selenite	Kd/w	s^{-1}	

Selenium Bioaccumulation through the Bivalves

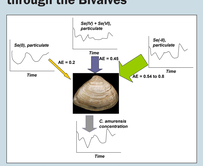


Figure 4. Bioaccumulation of Particulate Selenium in Bivalves

Model Boundary Conditions and External Loads

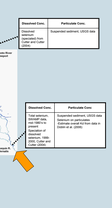
The riverine inputs of flow from Sacramento River at Rio Vista are DAYFLOW records from the Interagency Ecological Program (IEP; http://www.iep.ca.gov/dayflow/rio.shtml). The San Joaquin River is modeled as a tributary, with flow derived as the difference between Net Delta Outflow Index (NDOI) and flow from the Sacramento River at Rio Vista (Figure 5).

Riverine inputs of TSM and chlorophyll a were modeled as flow multiplied by concentrations (Figure 6). TSM concentrations were modeled as a function of flow. Riverine chlorophyll a concentrations were observed data from USGS and Bay Delta and Tributary Project (BDAT).

Dissolved selenium inputs for selenate, selenite, and organic selenide were specified from the rivers as flow and selenium concentrations by species from two rivers (Figure 5). Different species of selenium concentrations were derived using fitted functions based on observed data by Cutter and Cutter (2004). Delta removal constants were used in converting observed selenium concentrations at San Joaquin River at Vernalis to concentrations at the confluence. Particulate concentrations were based on data published by Doblin et al. (2006).

Selenium loads to the NSFB include point sources from refineries, municipal and industrial dischargers and tributaries. Point and non-point sources of selenium were added to the model domain at their discharge locations. Over the past two decades, there have been major declines in refinery loads due to improved wastewater treatment installed in 1998 and there is some evidence that San Joaquin River concentrations were lower in the late 1990s and beyond than in the 1980s.

Riverine inputs of selenium are the largest source to the NSFB (Figure 7).


Flow
Dissolved Se
Particulate Se
Dissolved Species
Selenate
Selenite
Organic Se
Particulate Species
Selenate
Selenite
Particulate Organic Se
Particulate Se
Dissolved Se
Phytoplankton
Bacteria
Organic Se
Particulate Se
BEPS
Particulate Se
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