Updates to ECoS3 to Simulate Selenium Fate and Transport in North San Francisco Bay

Prepared for:

Regional Water Resources Control Board, with funding support from the Western States Petroleum Association

Prepared by:

TETRA TECH

3746 Mt. Diablo Blvd., Suite 300
Lafayette, CA 94549

February 12, 2015

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Executive Summary

This document presents an update of a one-dimensional estuary model for simulating selenium dynamics within the North San Francisco Bay, employing recent data on selenium loads and estuary concentrations. Using calibrated values for important parameters, the model was found to be effective at representing the behavior of multiple selenium species in the dissolved and particulate phases, as measured through multiple transect sampling events from 1999 to 2012. Specifically, the model represented dissolved selenium in the water column (found in three different forms, selenate, SeVI, selenite, SeIV, and organic selenide, Se-II) and suspended particulate selenium (elemental selenium, Se0, adsorbed SeVI and SeIV, and organic selenide). Although the quantities of the individual selenium species are variable in time and space, and not all local-scale variations can be captured by the model, the essential features of the data are well-represented over multiple events, representing different years and seasons. Given the complexity of the San Francisco estuary hydrodynamics and of selenium biogeochemistry, and the quantity of data available for calibration, the model is an effective representation of the underlying process. The model can serve to mechanistically evaluate the effects of significant changes in the system, such as the modification of major loads, or the effects of different hydrologic conditions and seasonal effects.

As a step toward testing the effects of load modification, the calibrated model was run with individual dissolved selenium load categories reduced to zero, to examine the resulting changes in dissolved and particulate selenium concentrations. Currently, model simulated dissolved selenium at a mid-estuary location (Carquinez Strait) is approximately 0.13 µg/L during the dry periods, with 0.03-0.036 µg/L coming from the refineries. Of this, more than 50% is selenate. Uptake of refinery inputs of dissolved selenium contributes about 0.02 µg/g of particulate selenium at Carquinez, about 3% of the baseline level. The following concentrations result under these loads in Carquinez Strait during a typical dry season (October, 1999):

- When refinery loads were reduced to zero, total dissolved selenium concentrations decreased by 29.8%, and total particulate concentrations by 3.0%.
- When riverine loads were reduced to zero, but refinery loads were included at their baseline levels, total dissolved selenium concentrations decreased by 21.5% , and total particulate concentrations by 3.2%.
- When all riverine, tributary, and point source loads were reduced to zero, total dissolved selenium concentrations decreased by 51.2 % , and total particulate concentrations by 6.3%.
- When the refinery loads are increased by a factor of two or five, the total dissolved selenium concentrations at Carquinez Strait increase by 30% and 119% respectively. In comparison, the particulate selenium concentrations increase by 4.5% and 18%. Likewise, when concentrations are decreased by removing all major sources, dissolved selenium concentrations decrease by 51.2%, and particulate selenium concentrations decrease by 6.3%.

- Additional scenarios, i.e., a 50% reduction in refinery loads and a 50% increase in San Joaquin River flows, show related behavior: a response in the dissolved concentrations and limited change in particulate concentrations.

The reason for the limited change in particulate selenium despite these large shifts in loads is related to the calibrated selenium uptake and release rates from the particulate phase. These rates limit the exchange between the dissolved and particulate phases, and are based on calibration to observed data. Overall, the uptake/release rates and residence times in the Bay are such that the particulate response is much smaller than the response in the dissolved phase concentrations. Were the residence times much longer, or the rates much higher, there would be closer relationship between dissolved and particulate phase changes. However, neither of these can be changed readily: the residence time is a property of the estuary and its freshwater flows, and the reaction rates are constrained by the simultaneous observations of dissolved and particulate selenium through the transects.

Overall, the model shows that the dissolved concentrations are sensitive to the load changes, but the particulate selenium changes are small. Given the calibrated particulate uptake/release rates embodied in the model—and these rates are constrained by the observed particulate and dissolved values over multiple transect sampling events—there is only a modest change in the particulate concentrations. Thus, the calculated Kd values, which are a ratio of the particulate to dissolved concentrations, show an increase as a result of major load reductions. The modeling framework presented in this memorandum is an alternative to the use of an equilibrium-type approach for relating dissolved and particulate concentrations, and considers the rate limitations in selenium uptake into particles. In addition to evaluating the estuary concentration changes as a function of inflowing loads, the model is also a temporally detailed representation of selenium processes under current loading conditions over 1998-2013, and can be used to explore changes in selenium speciation and distribution under changing hydrology over this period.

1 Introduction

A previously developed numerical model for simulating selenium transport and transformation in the North San Francisco Bay (NSFB) (Tetra Tech, 2010; Chen et al., 2012) was updated with more recent flow and selenium inputs. The modeling was performed with transformation rates that were same as those used in the previous work and updates in Tetra Tech (2012). The components modeled include salinity, total suspended material (TSM), dissolved selenium species (selenate, SeVI; selenite, SeIV; organic selenide, OrgSe), and particulate selenium species (selenate plus selenite, PSeIV+VI; organic selenide, POrgSe; and elemental selenium, PSe0).

A major change from the previous modeling is the use of the DSM2 model[1] to simulate selenium inputs from the Sacramento and San Joaquin Rivers in the present work, along with the most recent updates of selenium inputs from the tributaries, refineries, and other point sources. The model was also extended to a more recent period of March 2013, using updated flow records. This report describes the process used for updating the model inputs to March 2013 and compares results to selenium observations presented in Tetra Tech (2012). Using the calibrated model, different selenium loading scenarios were evaluated, with a focus on changes in the dissolved and particulate concentrations, and in the ratio between the two quantities.

1.1 Flow and Hydrodynamic Modeling

Precipitation and Evaporation

Precipitation input to the bay was extended to March 2013 using daily data from California Irrigation Management Information System (CIMIS; *http://wwwcimis.water.ca.gov/cimis/data.jsp*) at a station near the San Francisco Bay (Station #109). Evaporation records were extended to March 2013 using data from the same CIMIS station.

Flow

Flow from the Sacramento River to the bay (Rio Vista) was updated to March 2013 using DAYFLOW data from the Interagency Ecological Program (IEP; *http://www.water.ca.gov/dayflow/output/*). The San Joaquin River flow input at the confluence with the Sacramento River at Antioch was calculated as the difference between the Delta outflow (Net Delta Outflow Index, NDOI) and the Rio Vista flow. The flow data in the Department of Water Resources databases are provisional in the latter part of the record, and sometimes updated at a future date. Such a change may occur in the future for data corresponding to 2011 and 2012.

[1] The DSM2 model, developed by the California Department of Water Resources, is widely used for simulating hydrodynamics and transport of conservative constituents through the Delta.

Tributaries

Napa River flow was extended to March 2013 using daily flow records from the USGS (*http://waterdata.usgs.gov/nwis*) at Napa River (USGS11458000, Napa River near Napa, CA).

1.2 Physical Parameters

Salinity, TSM and Chlorophyll a

Approximately 21 stations in the NSFB were sampled by USGS for salinity, TSM, and chlorophyll a (*http://sfbay.wr.usgs.gov/access/wqdata/*) on a monthly basis through monthly cruises to the Bay. The USGS data together with transect sampling were used to evaluate modeled salinity, TSM, and chlorophyll *a* for the period of 2009-2012.

1.3 Boundary Conditions

Flow

Flow boundary conditions at Rio Vista (Sacramento River) and San Joaquin River inputs were extended to March 2013, using data obtained from IEP, as discussed above.

Physical Parameters

Boundary conditions for physical parameters (TSM, chlorophyll a) at Rio Vista were extended to March 2013 using observed monthly data at Rio Vista from USGS bay cruises sampling. Boundary conditions for physical parameters at Golden Gate were extended using data collected from USGS bay cruises sampling.

Selenium Data

Sacramento River

In the estuary model, selenium inputs to the Bay from the Sacramento and the San Joaquin River were estimated as total inputs from the Sacramento River at Rio Vista and San Joaquin River at confluence (Antioch). In this update, dissolved selenium inputs from the Sacramento River to the Bay (at Rio Vista) were modeled using the DSM2 model, and assuming that the transport of selenium through the Delta can be approximated as a conservative constituent.

The DSM2 model estimates the volumetric contributions from several riverine sources including the Sacramento River at Freeport, San Joaquin River at Vernalis, east side tributaries, Yolo Bypass and agricultural returns. Dissolved selenium concentrations at Rio Vista are the result of water mixing from these sources. In estimating dissolved selenium concentrations at Rio Vista, the DSM2 model predicted volumetric contributions from source boundaries and dissolved selenium concentrations at these boundaries were used. Dissolved selenium concentrations from the Sacramento River at Freeport were data collected by the USGS for the period of 2007-2013 (Figure 1-1). Dissolved selenium concentrations from San Joaquin River at Vernalis were also collected by the USGS (Figure 1-2). Dissolved selenium concentrations for the east side tributaries and agricultural returns used in calculation are constant values of 0.1 and 0.11 µg/L. A detailed description of modeling using DSM2 to estimate dissolved selenium inputs to the Bay is presented in Technical Memorandum D to the Regional Board.

The speciation data used in the modeling for Sacramento River inputs are data reported in Cutter and Cutter (2004) and Tetra Tech (2012) for Sacramento River at Freeport. Data collected by Cutter and Cutter (2004) were monthly values for the period of 1984-1988 and 1998-2000. Data collected by Tetra Tech (2012) are for four sampling events during 2010-2012. Data gaps exist between 2000-2010. To fill the data gaps, fitted sine wave functions based on existing data were used to generate speciation data for the dissolved selenium (following the approach of Meseck and Cutter, 2006). The equation and parameters used to generate the speciation data are listed in Table 1-1. Particulate selenium concentrations measured at the Sacramento River at Freeport ranged from 0.47 – 1.40 µg/g and are limited to a small number of samples. Particulate selenium concentrations at boundaries used in the model are values at Freeport sampled by Tetra Tech (2012) during the four sampling events. A high flow and a low flow average for different species were derived based on the sampling results and were used in the model (Table 1-1).The actual values used in the model therefore fluctuate between high flow and low flow averages.

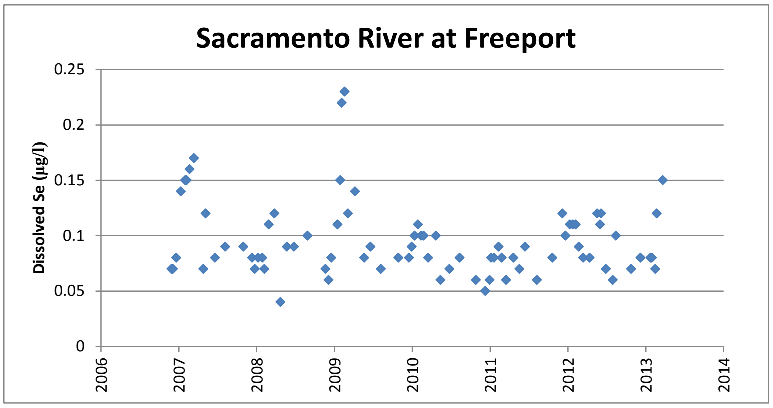


Figure 1-1
Total dissolved selenium concentrations at Sacramento River at Freeport (data source: USGS NWIS).

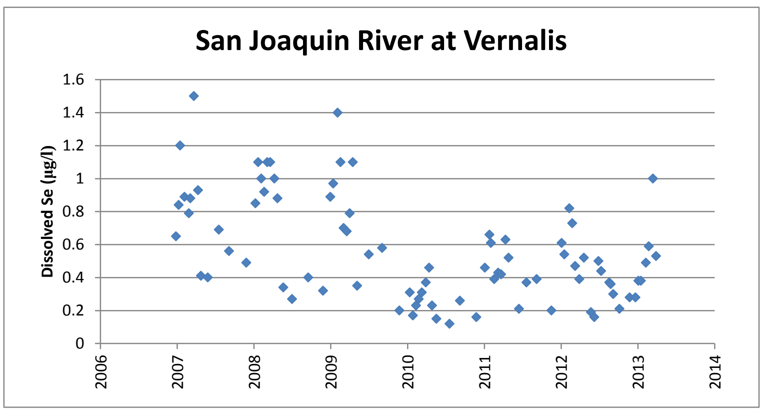


Figure 1-2
Total dissolved selenium concentrations at San Joaquin River near Vernalis (data source: USGS NWIS).

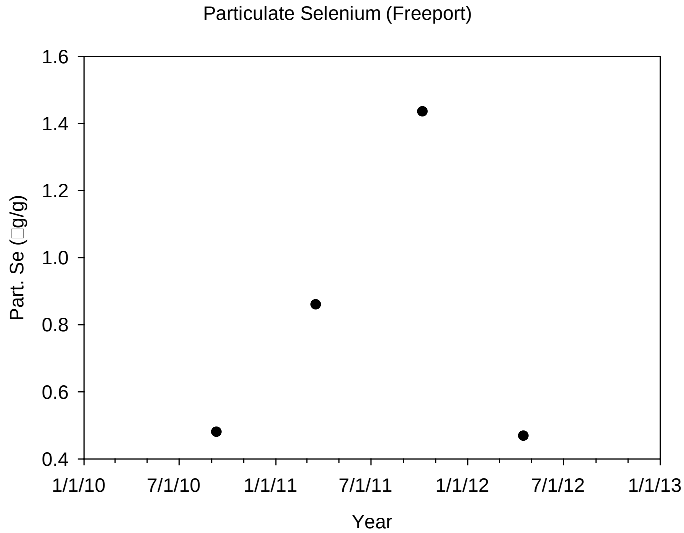


Figure 1-3
Particulate selenium concentrations at Sacramento River at Freeport sampled by Tetra Tech (2012).

Table 1-1
Parameters used to generate dissolved selenium speciation at Sacramento River at Rio Vista

Species	yo	a	b	c	Equation
Se IV	0.095	0.05	175	0.65	SeIV = yo + a*SIN(2π*T/b +c) T: days from starting date
Se VI	0.5	0.3	175	0.65	SeVI = yo + a*SIN(2π*T/b +c) T: days from starting date
Organic Se	0.35	0.25	315	0.75	SeII = yo + a*SIN(2π*T/b +c) T: days from starting date

Table 1-2
Particulate selenium concentrations at boundary (Freeport) sampled by Tetra Tech (2012).

	Part Se (µg/g)	PSeivvi (µg/g)	PSe0(µg/g)	POrgSe (µg/g)
10-Sep-2010	0.48	0.05	0.05	0.48
18 Mar 2011	0.86	0.13	0.01	0.73
7 Oct 2011	1.44	0.31	0.02	1.12
16 Apr 2012	0.47	0.47	0.07	0.00
Low flow average	0.96	0.18	0.03	0.80
High flow average	0.66	0.10	0.01	0.56
Average	0.81	0.14	0.02	0.68

San Joaquin River

Total dissolved selenium concentrations at San Joaquin River at the confluence with Sacramento River (Antioch) were estimated from DSM2. The estimated volumetric contribution and concentrations from boundaries were used to estimate selenium concentrations at the confluence.

Application of DSM2 to estimate selenium inputs to the Bay is described in Technical Memorandum D to the Regional Board.

The speciation of dissolved selenium for San Joaquin River at the confluence was based on data reported by Cutter and Cutter (2004) and Tetra Tech (2012) for the San Joaquin River at Vernalis. Inputs of particulate selenium from Vernalis were associated with dissolved selenium through Kd values for particulate selenite and selenate and particulate organic selenium, derived based on the observed data. Particulate elemental (PSe0) concentrations from the San Joaquin River at Vernalis were constant values, as suggested by data collected by Tetra Tech (2012). Total particulate selenium concentrations in San Joaquin River at Vernalis generally ranged from 0.87–1.48 µg/g.

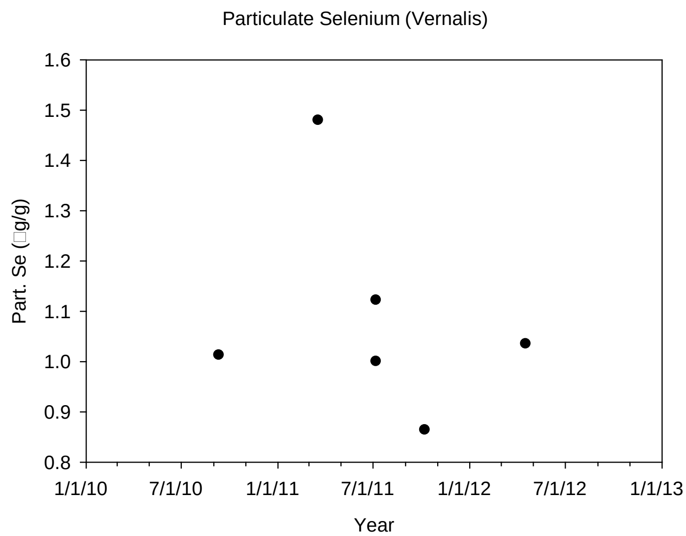


Figure 1-4
Particulate selenium concentrations at San Joaquin River at Vernalis sampled by Tetra Tech (2010).

Golden Gate

Dissolved and particulate selenium concentrations measured at Golden Gate from previous studies (Cutter and Cutter, 2004; Doblin et al. 2006) and Tetra Tech (2010) were used as the boundary concentrations for Golden Gate.

1.4 Inputs from Refineries

Daily total selenium loads from five refineries were extended to the end of 2012 using flow and selenium data obtained from the dischargers. Details of refinery load calculation were documented in another memorandum. The calculated daily selenium load was used as input to ECoS3 model.

Monthly effluent samples were collected from five refineries to estimate dissolved and particulate selenium species, for the period of September 2010–August 2011(Tetra Tech 2012, Figure 1-5). This information was used to assign selenium speciation for the refinery inputs. Refinery speciation sampled for the period of 1999–2000 by Cutter and Cutter (2004) was also used in the model for the period of 1999–2000 and 2000–2010. Since particulate selenium concentrations from the refineries were also sampled (Tetra Tech 2012), these were also included as model inputs.

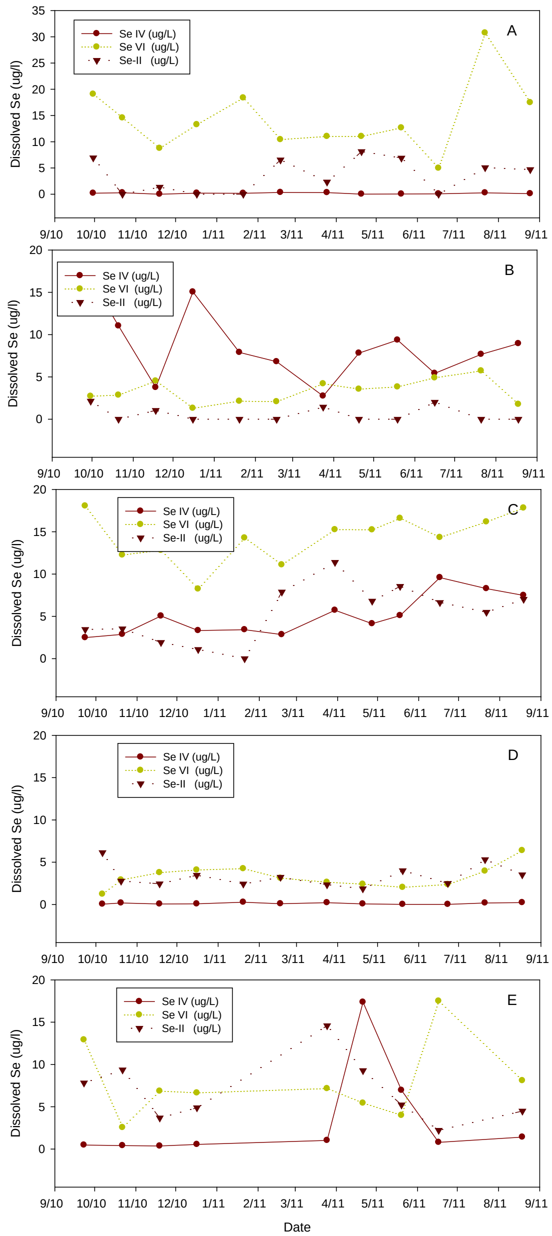


Figure 1-5
Speciation of dissolved selenium in effluents of five refineries (Tetra Tech 2012).

1.5 Inputs from Municipal and Industrial Dischargers

Unlike the previous modeling effort, where municipal and industrial discharges were set as constant, time-series inputs were used for this study. Daily total selenium loads for municipal and industrial dischargers were calculated for the period of 2008–2012 and for the period before 2008, using flow and selenium data obtained from SFBRWCB. Daily total selenium loads from the major municipal dischargers are shown in Figure 1-6. For periods after 2012, a constant value of estimated average daily selenium loads was used.

Speciation of selenium from municipal and industrial discharges was assumed to be the same as refinery discharges, which are set as constant average values.

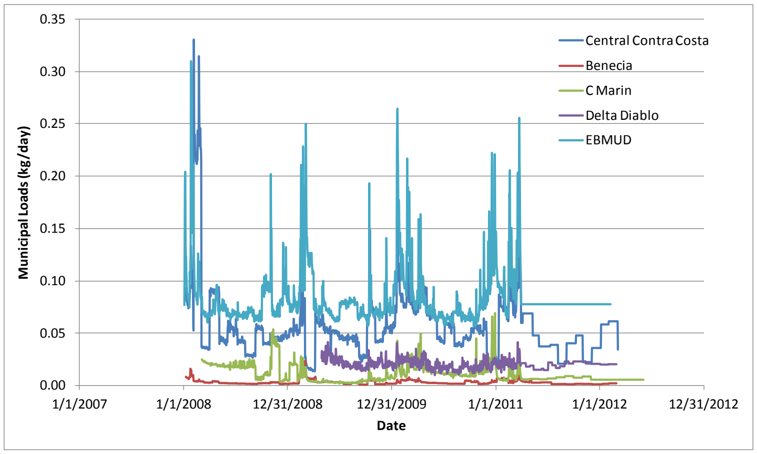


Figure 1-6
Examples of daily total selenium loads from the major municipal dischargers for the period of 2008–2012.

1.6 Inputs from Tributaries

Inputs from the tributaries were specified as flow multiplied by concentrations. Daily flow from Napa River was used to scale for tributaries without long-term flow records, based on modeled total runoff for each tributary (Davis, 2000). Dissolved and particulate selenium concentrations from the tributaries were sampled during March 2012 sampling event by Tetra Tech (2012) and by SFEI at a few locations in tributaries draining into North San Francisco Bay (Appendix B). These concentrations were used as model inputs together with limited information on particulate selenium speciation from the tributaries. Total selenium concentrations sampled during this study were somewhat lower than previous data collected within these watersheds by SWAMP program (Figure 1-7).

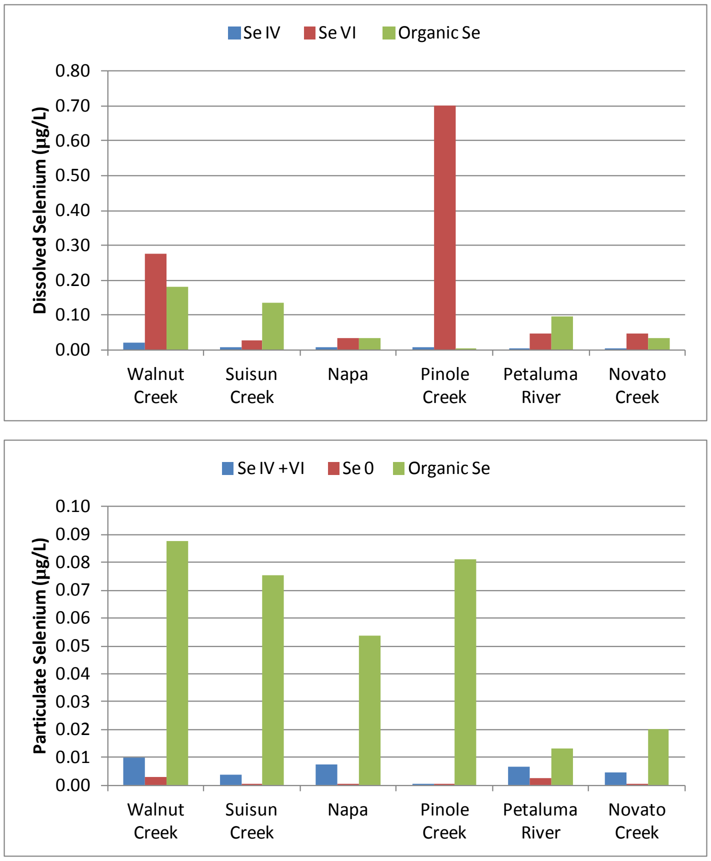


Figure 1-7
Dissolved and particulate selenium concentrations by species for six tributaries sampled during April 2012.

2 Modeling Approach

The modeling was performed using the ECoS framework as previously reported (Tetra Tech, 2012, Chen et al., 2012). Key features and updates to the modeling approach are presented below.

Salinity

The salinity and dissolved selenium species are now modeled using a dispersion coefficient derived from the following equation, by assuming steady-state for each time step (Tetra Tech, 2012):

$$0 = -U\frac{dS}{dx} + E\,\frac{d^2S}{dx_2} \qquad (1)$$

Where S is salinity at distance x, U is velocity and E is the dispersion coefficient. E was estimated as a function of distance through this procedure.

TSM

Simulation of BEPS (Bed Exchangeable Particles) was recalibrated for the period of 2008–2012 in the previous modeling update (Tetra Tech, 2012). The parameters for simulating velocity (a, b) and dispersion coefficient (c, d) of BEPS therefore changed from the earlier model.

The fraction of PSP (Permanently Suspended Particles) at Rio Vista was specified as 0.85, as in the previous model. The value was based on and equivalent to the fraction of suspended sediments with diameter less than <0.0625mm, which is expected to be largely in the suspended phase.

Selenium Transformations

The selenium transformation rate constants used in this updated model application remained unchanged from previous model update (Tetra Tech, 2012).

Model Validation

The model was simulated for the entire time period from June 1998- March 2013. Model-simulated results and the four transects sampled during this study for salinity, TSM, phytoplankton, dissolved and particulate selenium species were compared. The model-simulated physical parameters including salinity, TSM, and phytoplankton were validated against the USGS monthly cruise data for the period of 2009–2012. Model simulated transects for the previous time periods (April 1999 and November 1999) were also compared to transect data sampled by Cutter and Cutter (2004) and Doblin et al. (2006).

Model Evaluation Criteria

In addition to the previous model evaluation criteria used (r, correlation coefficient and goodness of fit, defined previously in Tetra Tech, 2010), several additional statistical measures were added to evaluate the quality of the model fit. These include:

MSE – The Mean Squared Error is a standard statistic that measures the bias between simulated and observed values. The optimal value is zero:

$$MSE = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2}{n} \right] \quad (2)$$

RMSE – The Root Mean Squared Error is a standard statistic used to indicate accuracy of the simulation. It is the square root of the MSE. The optimal value is zero.

PBIAS – Percent bias measures the average tendency of the simulated data to be larger or smaller than the measured data. A value of 0 of optimal – a positive value indicates underestimation bias and a negative value indicate overestimation bias:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right) * 100}{\sum_{i=1}^{n} \left(Y_i^{Obs} \right)} \right] \quad (3)$$

The calibration of the model is presented in Appendix A. The 2010-2012 transect data are the basis of the calibration, and are followed by validation for the 1999 data.

3 Modeling Results

This section is focused on the exploration of scenarios that consider the effect of changing loads, both increases and decreases, on specific concentrations in the water column, suspended particulates, and biota. The following scenarios are shown:

- The effect of individual loads is examined by selectively turning off the loads, i.e., setting the dissolved concentrations to zero for one or more selenium sources. The specific load reductions considered below are: refinery loads, riverine loads, and all point-source loads and riverine/tributary loads.
- We performed a run using constant boundary concentration conditions that isolated the effect of changing hydrology on the modeled concentrations.
- We considered a scenario with a 50% reduction of refinery loads.
- The effect of increased loads from petroleum refineries is shown by increasing their loads by a factor of two and a factor of five.
- The effect of increased loads from San Joaquin River is shown by allowing greater inflows into the Bay.
- A natural load scenario is considered where all inflows are set to the background levels in the Sacramento River, and where the San Joaquin River is set at 0.2 μg/l.

The model scenarios presented here may be considered extreme from a load reduction or load increase perspective, and are not intended for actual implementation, but to illustrate the importance of individual load categories in determining estuary concentrations.

3.1 Seasonal Average Concentrations

Modeled average concentrations of dissolved and particulate selenium at Carquinez Strait by month for baseline conditions are shown in Figure 3-1. In general the concentrations show modest changes over the seasons, although the loads may change from month to month. In particular, dissolved concentrations are about 20% higher in a dry month such as August or September, compare to a wet month such as January. Particulate concentrations, expressed as μg/g show a larger seasonal range, and the high values in fall (e.g., November) are about 50% higher than the low values in March. This is related to the composition of the particulate material in the Bay, with higher selenium associated with more organic rich particulates. There is a greater fraction of organic-rich particulates in the dry seasons as compared to the wet seasons, which show a greater signal of the riverine and lower-organic particulate load.

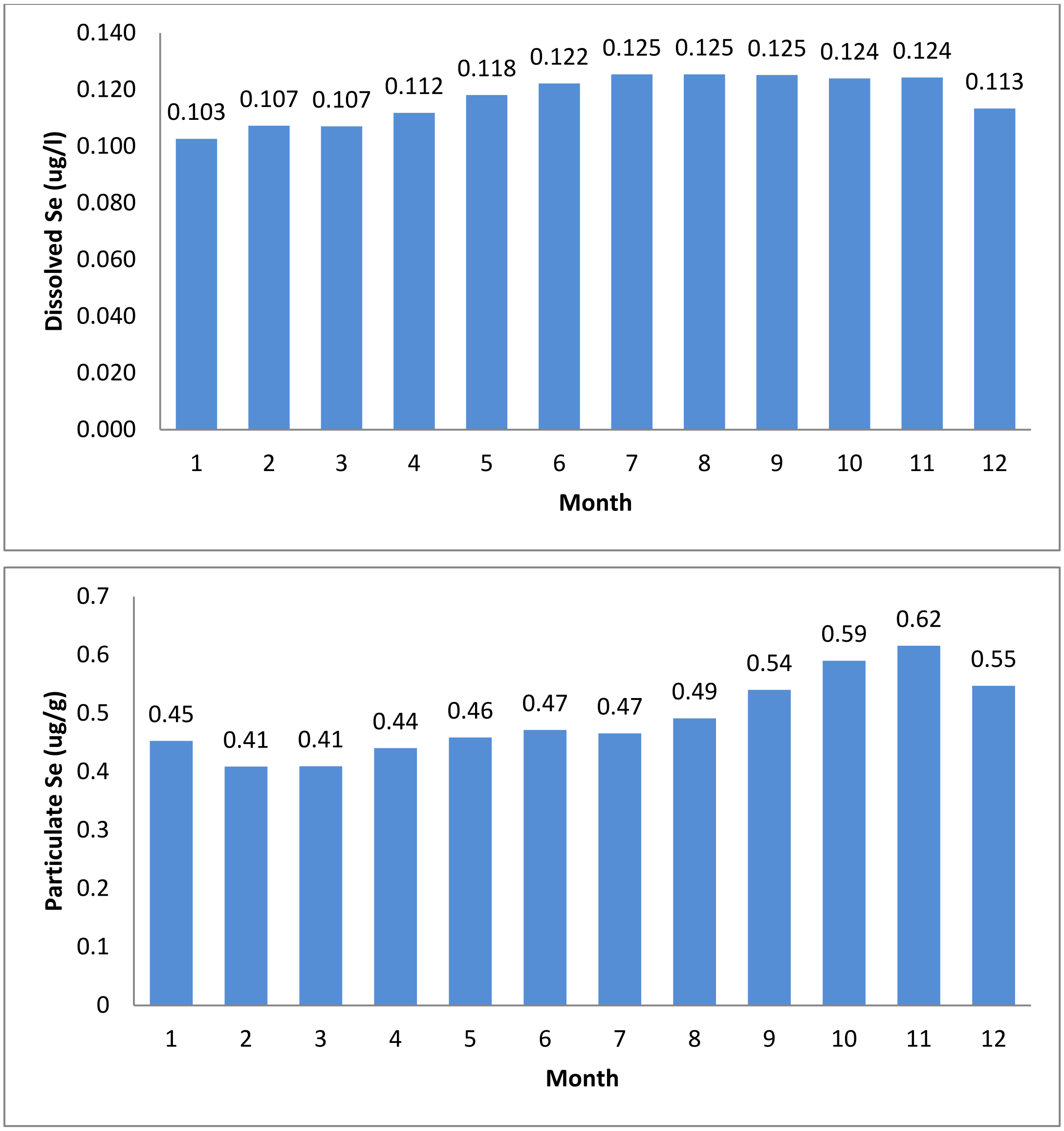


Figure 3-1
Modeled average concentrations of dissolved and particulate selenium, averaged over 1998-2012, for each month. Note the different units for dissolved and particulate selenium.

3.2 Mass Balance Calculations for North San Francisco Bay

As a first step the model calculations for the North Bay were performed for the 1998-2012 simulation period with current levels of loading from point- and non-point sources. Averages of the loads for the wet and dry months over the entire simulation period are shown in Figure 3-2 for total selenium and in Figure 3-3 for dissolved selenium. Over this averaging period, wet season loads are higher than the dry season loads, and the difference is largely related to the greater riverine loads, representing inputs to the Bay from the Delta, and from the tributary loads, which are largely non-existent in the dry months. Also, the difference between the total and dissolved fluxes is small, indicating that much of the loads are in the dissolved form. The estimated flux of selenium exiting the Bay through Golden Gate is displayed as a separate bar in these plots, and is roughly equal to the in inflowing fluxes. On a long-term average basis, virtually all of the selenium load entering the Bay is also transported out into the Pacific Ocean.

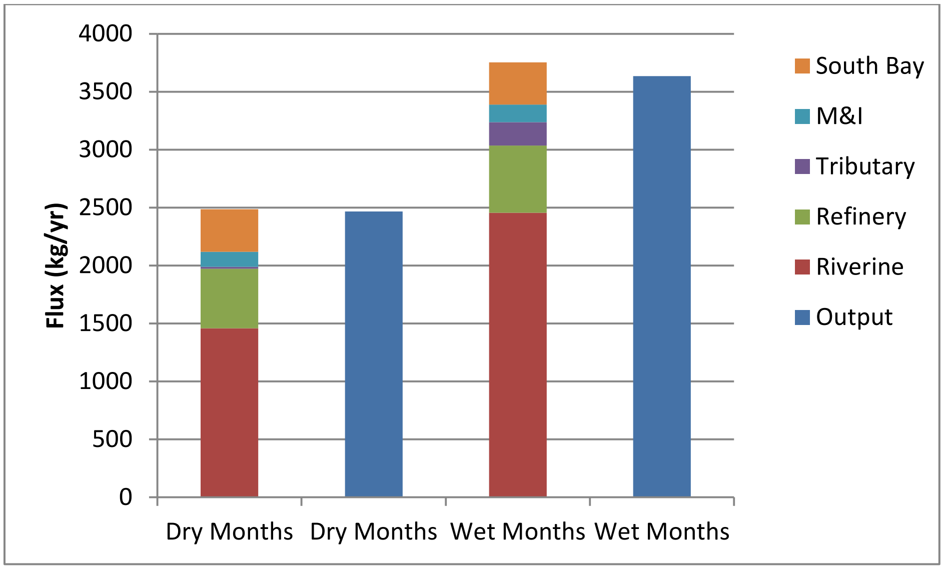


Figure 3-2
Annual fluxes of total selenium (dissolved and particulate) during the dry and wet months of the 1998-2013 simulation period (wet = October through April, and dry = May through September). M&I refers to municipal and industrial discharges. Output refers to loads exiting the Bay through Golden Gate.

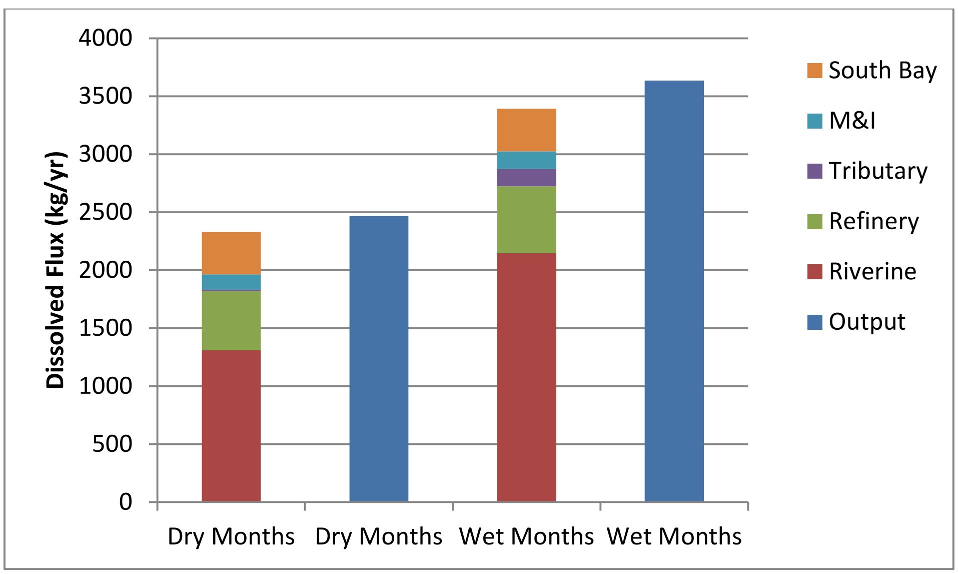


Figure 3-3
Annual fluxes of dissolved selenium during the dry and wet months of the 1998-2013 simulation period (wet = October through April, and dry = May through September). M&I refers to municipal and industrial discharges. Output refers to loads exiting the Bay through Golden Gate.

3.3 Effects of Load Reductions

Effects of Refinery Load Reductions

The effects of refinery loads on water quality in the North Bay were evaluated by reducing dissolved selenium loads from refineries to zero. The particulate selenium loads from refineries are small, and for the purpose of this evaluation remained unchanged.

Figure 3-4– Figure 3-6 shows the results of reducing refinery loads to zero for the simulation period of 1998-2012. Without refinery inputs, selenite concentrations showed a reduction of 0.005-0.007 µg/L during low flow. Selenate concentrations showed a reduction of 0.02 µg/L, and organic selenide showed a reduction of 0.005-0.01 µg/L. The model simulated Kd (expressed as particulate selenium in µg/g over total dissolved selenium in µg/L) showed large seasonal and inter-annual variations. Simulated Kd values are higher under no refinery loads scenario due to decrease in dissolved selenium under no refinery loads, and relatively small change in particulate selenium (Figure 3-7).

On a monthly average basis, selenite showed 0.003- 0.005 µg/L decrease for different months due to refinery reduction (Figure 3-8). Selenate showed a decrease of 0.01 – 0.02 µg/L for different months. Organic selenide showed a decrease of 0.005 – 0.007 µg/L. The changes in dissolved selenium concentrations are most significant during low flow months of September to November. Particulate selenium as a result showed monthly average changes of 0.001 – 0.007 µg/g for different months due to refinery load reductions (Figure 3-9). Selenium concentrations in clams showed a change of 0.025 to 0.20 µg/g for different months (Figure 3-10).

The linkage between dissolved and particulate selenium was evaluated for a no refinery scenario using the model at three locations: Suisun Bay, Carquinez Strait and San Pablo Bay for a dry period transect: Oct. 30, 1999.

At Suisun Bay, the model simulated total dissolved selenium concentration is 0.091 µg/L, of this 0.013 µg/L is contributed by refinery inputs (Table 3-1). The refinery contribution of dissolved selenium is dominated by selenate (0.006 µg/L), with a lower contribution from organic selenide and selenite (0.002 -0.003 µg/L). The dissolved selenium from refineries contributes up to 0.005 µg/g of particulate selenium in Suisun Bay due to uptake of dissolved selenium from refineries.

At Carquinez Strait, the model simulated total dissolved selenium concentration is 0.121 µg/L, of this 0.036 µg/L is contributed by refinery inputs (Table 3-2). The refinery contribution of dissolved selenium is dominated by selenate (0.020 µg/L), with a lower contribution from organic selenide and selenite (0.006 -0.009 µg/L). This contributes up to 0.021 µg/g of particulate selenium in Carquinez Strait due to the uptake of dissolved selenium from refineries.

At San Pablo Bay, the model-simulated total dissolved selenium concentration is 0.101 µg/L, of this 0.02 µg/L is contributed by refinery inputs (Table 3-3). The refinery contribution of dissolved selenium is dominated by selenate (0.012 µg/L), with the contribution from organic selenide and selenite at 0.004 - 0.005 µg/L. This contributes up to 0.026 µg/g of particulate selenium in San Pablo Bay due to uptake, out of a baseline value of 0.872 µg/g.

The results are shown in Figure 3-11 for three dry season transects. The results suggest that without refinery dissolved inputs, simulated particulate selenium concentrations in the Bay decreased by up to 0.02 µg/g, depending on phytoplankton concentrations and residence time.

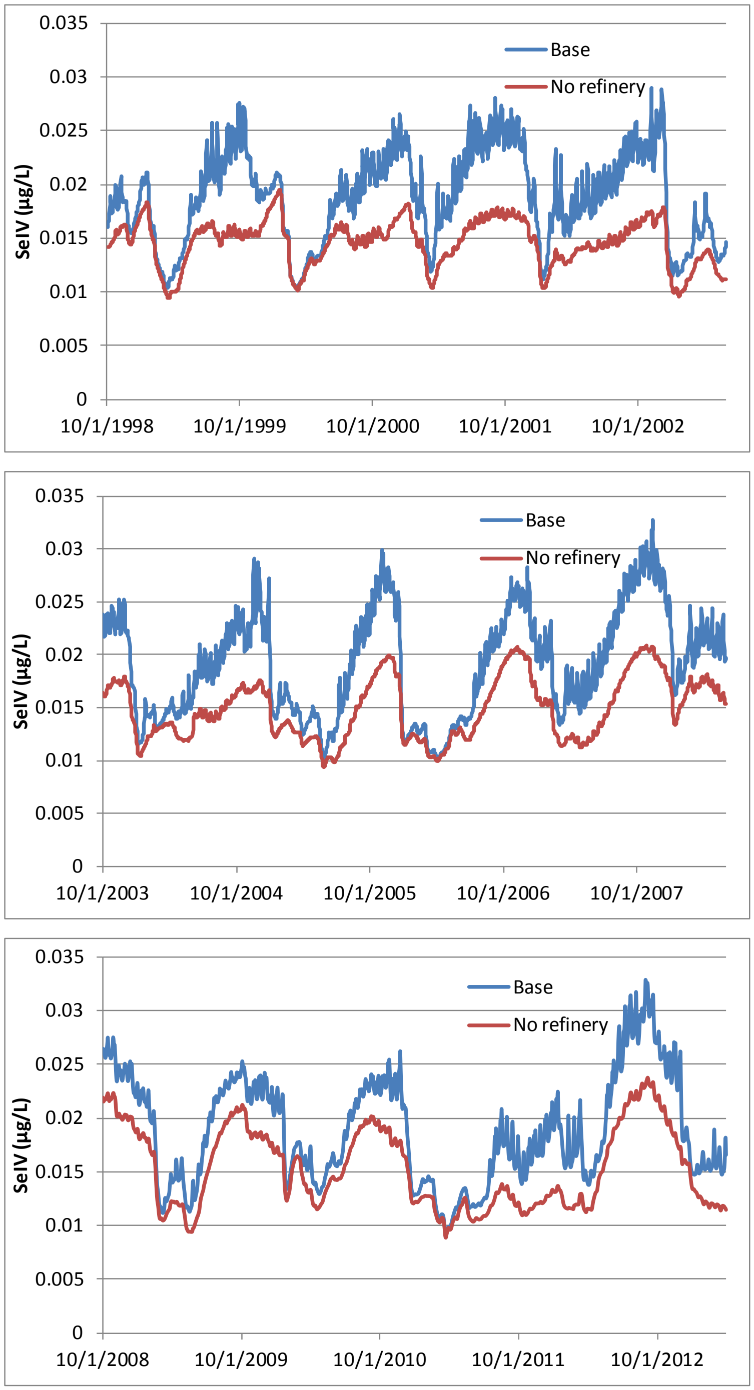


Figure 3-4
Simulated concentrations of selenite under current conditions and no refinery scenario at Carquinez Strait.

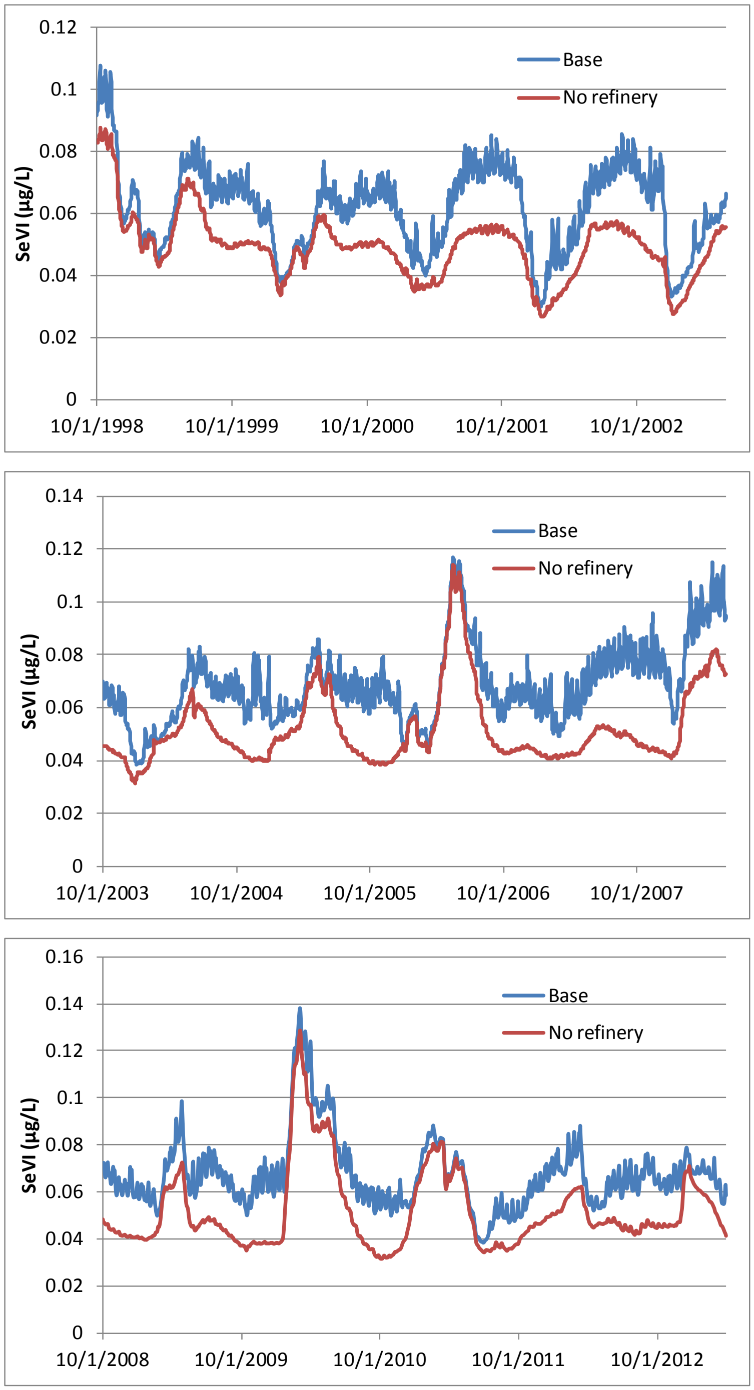


Figure 3-5
Simulated concentrations of selenate under current conditions and no refinery scenario at Carquinez Strait.

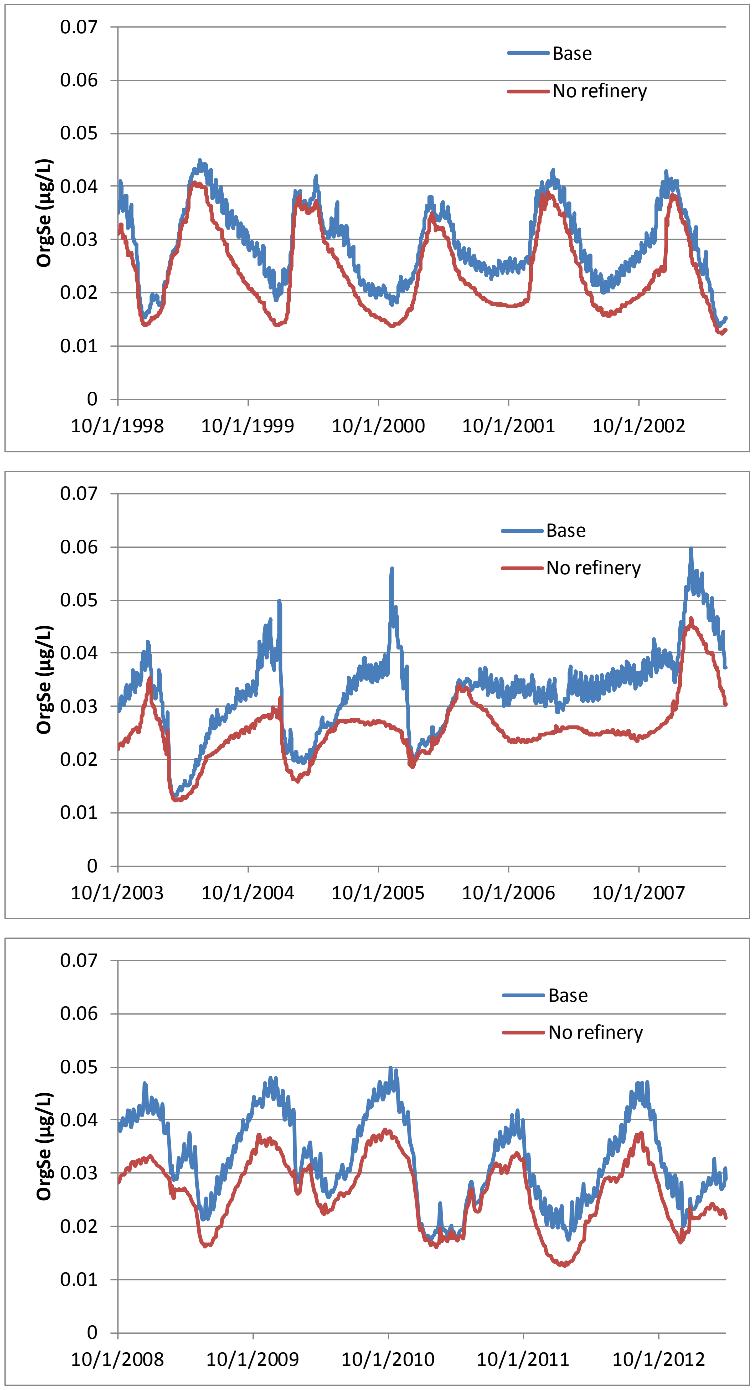


Figure 3-6
Simulated concentrations of organic selenide under current conditions and no refinery scenario at Carquinez Strait.

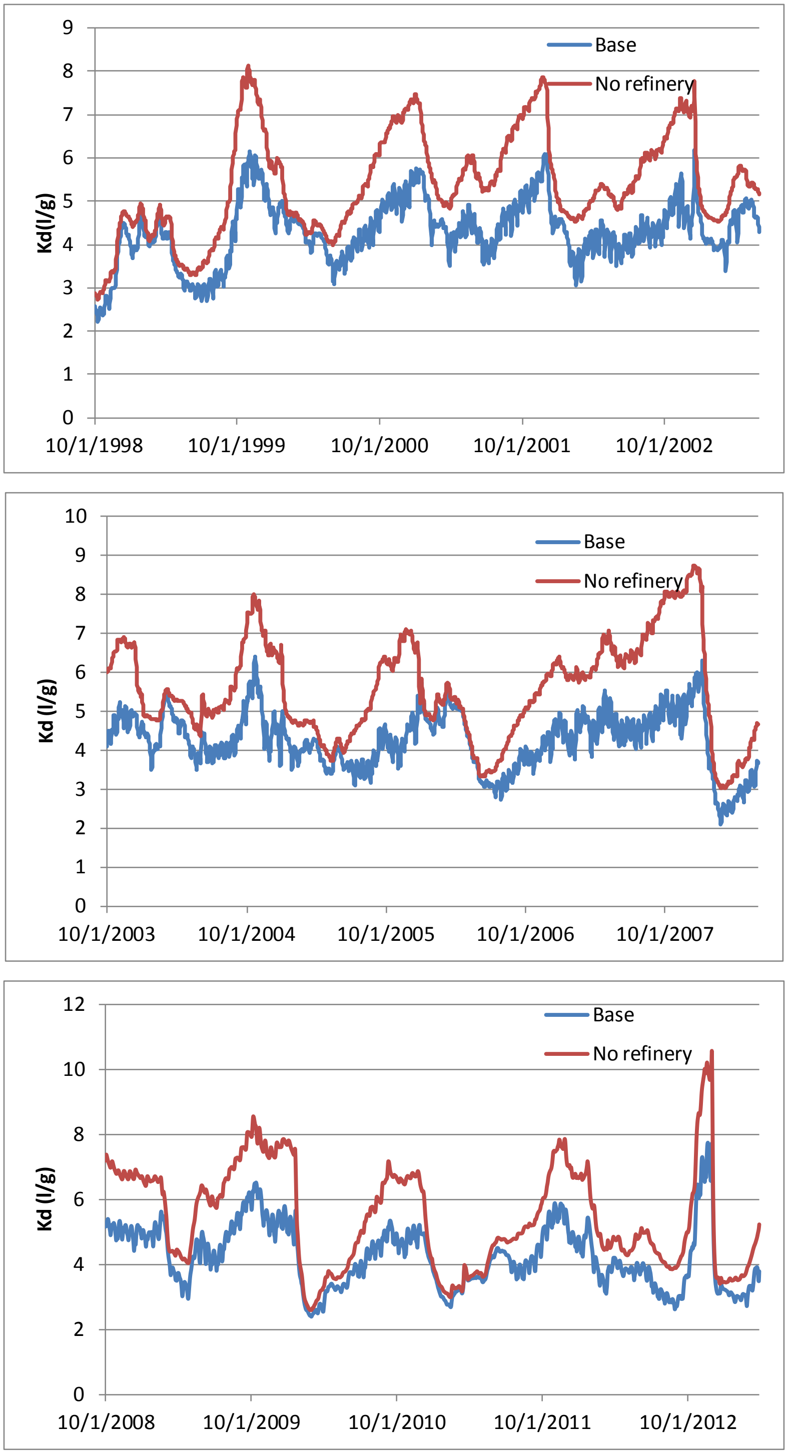


Figure 3-7
Simulated Kds under current conditions and the no refinery scenario at Carquinez Strait.

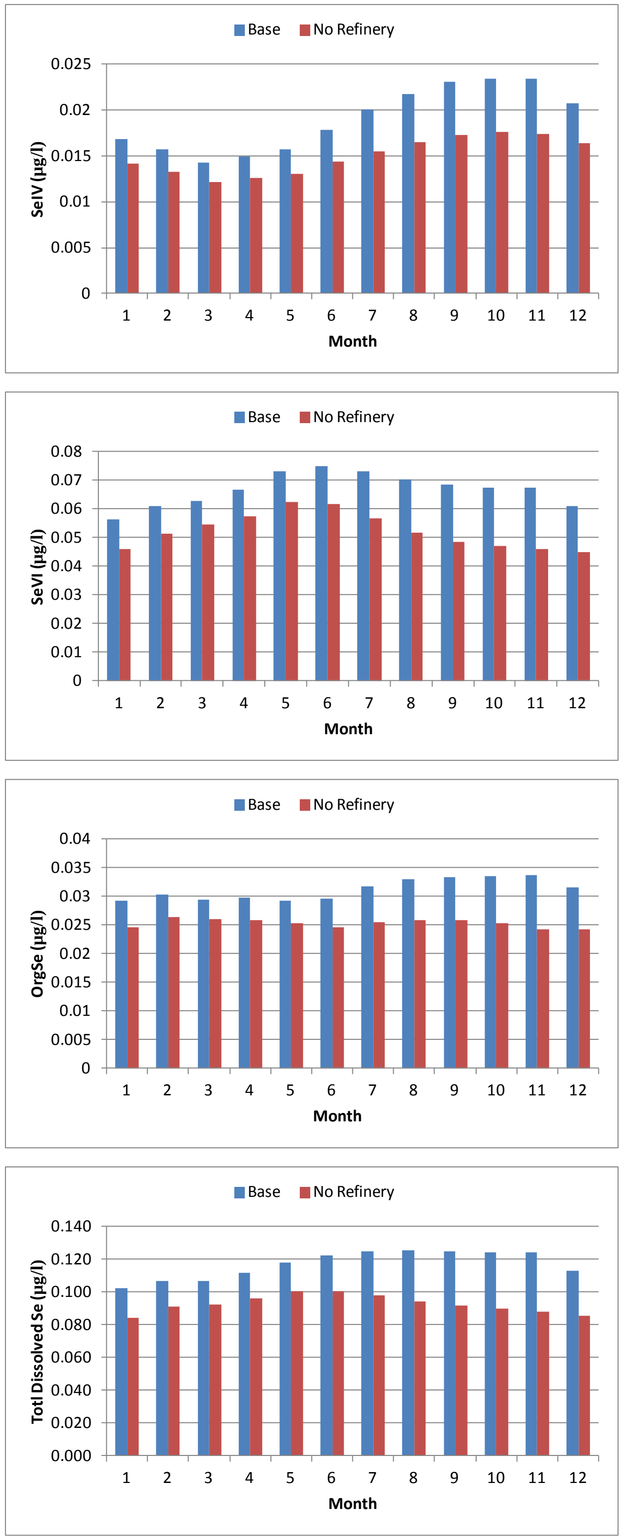


Figure 3-8
Simulated concentrations of dissolved selenium under current conditions and no refinery scenario at Carquinez Strait.

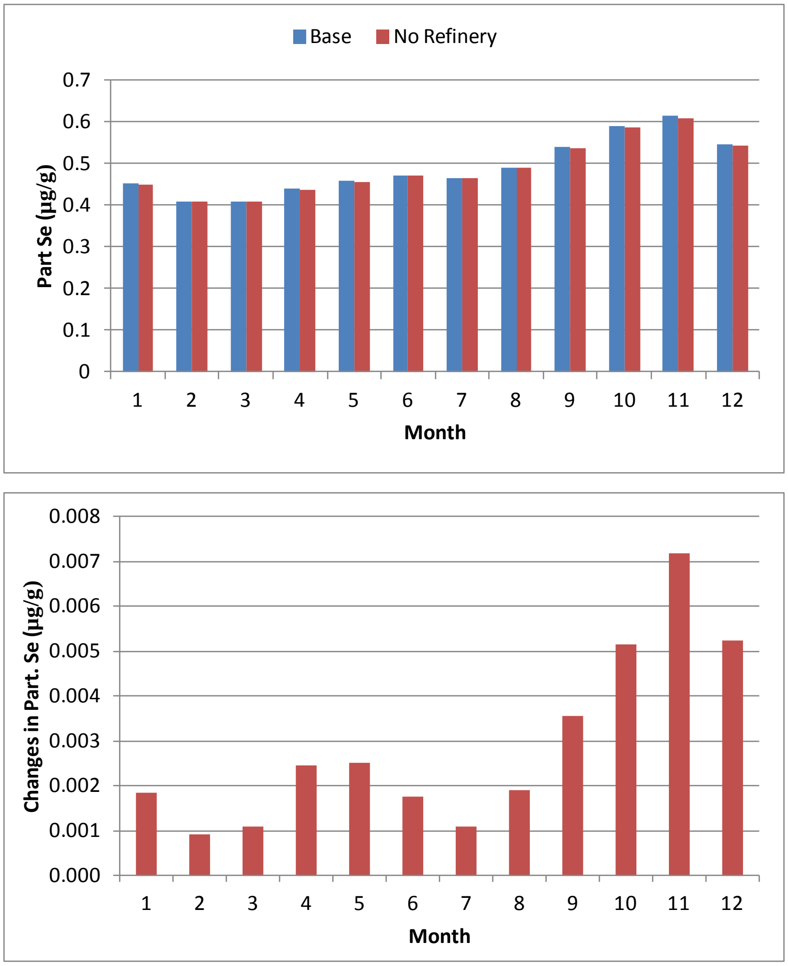


Figure 3-9
Simulated changes in particulate selenium due to refinery load reductions at Carquinez Strait.

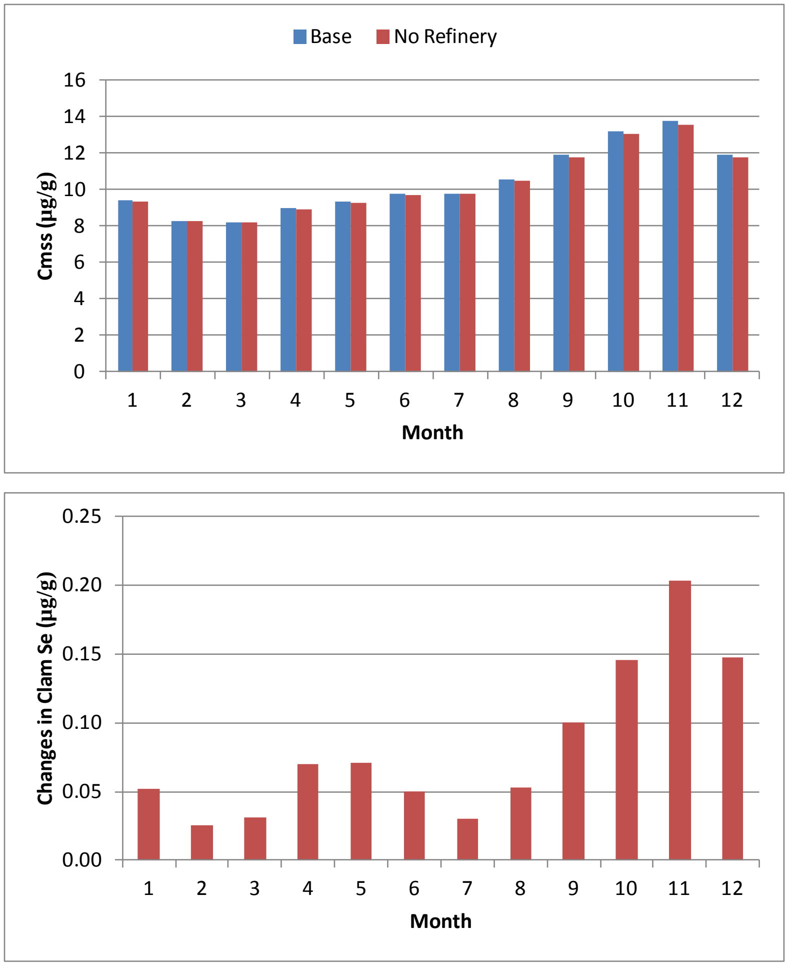


Figure 3-10
Simulated changes in clam selenium concentrations due to refinery load reductions at Carquinez Strait.

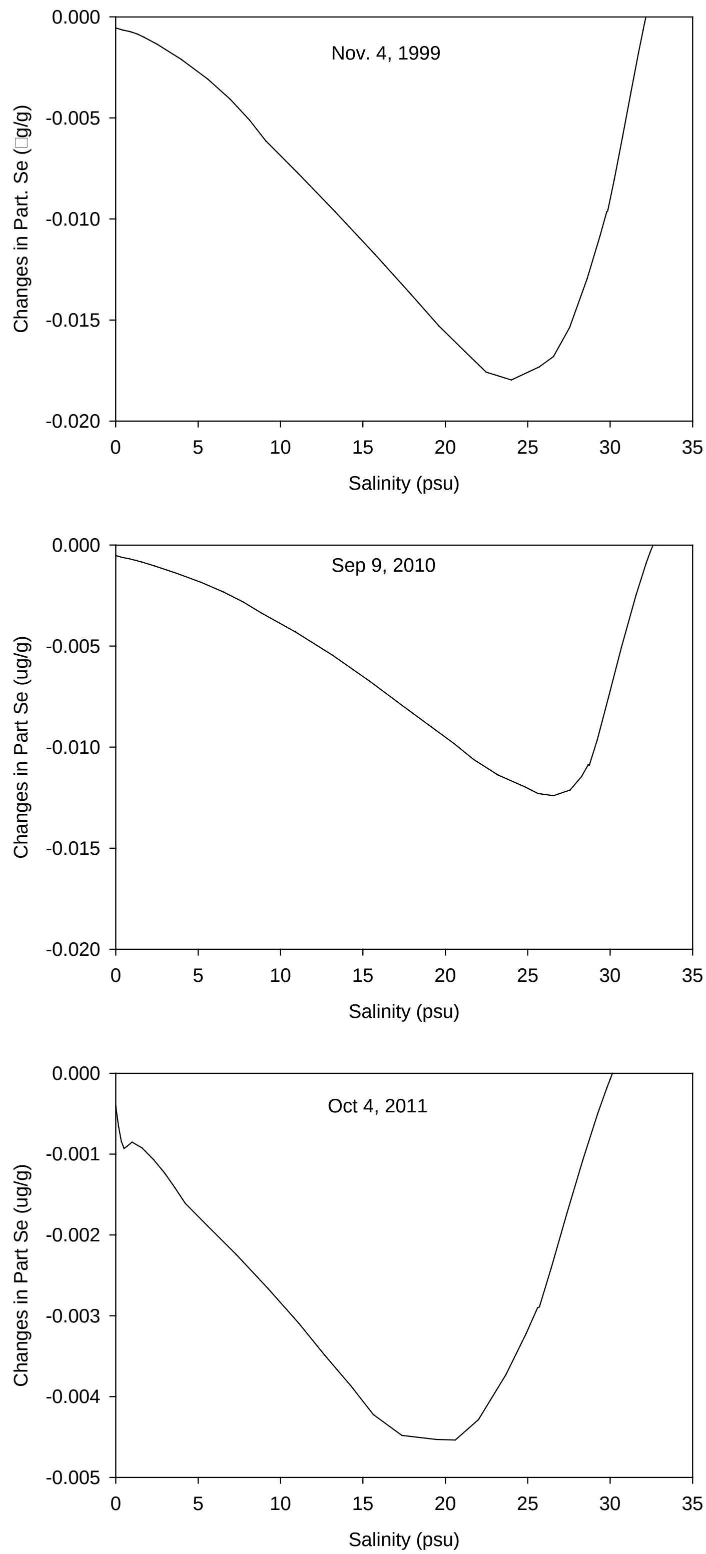


Figure 3-11
Model simulated changes in particulate selenium by setting refinery loads to zero.

Table 3-1
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to refinery dissolved selenium load reduction for the Oct. 30, 1999 transect.

Species	Base Case	No Refinery	Change	% Change
Total Dissolved	0.091 (0.014 SeIV, 0.057 SeVI, 0.02 OrgSe)	0.078 (0.011 SeIV, 0.050 SeVI, 0.017 OrgSe)	-0.013 (0.002 SeIV, 0.006 SeVI, 0.003 OrgSe)	-14.3
Total Particulate (µg/g)	0.563 (0.328 POrgSe, 0.118 PSeivvi, 0118 PSe0)	0.558 (0.323 POrgSe, 0.117 PSeivvi, 0.11 PSe0)	-0.005 (0.005 POrgSe, 0 PSeivvi, 0 PSe0)	-0.9

Table 3-2
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to refinery dissolved selenium load reductions for the Oct. 30, 1999 transect.

Species	Base Case	No refinery	Change	% Change
Total Dissolved	0.121 (0.02 SeIV, 0.07 SeVI, 0.03 OrgSe)	0.085 (0.016 SeIV, 0.05 SeVI, 0.02 OrgSe)	-0.036 (0.006 SeIV, 0.02 SeVI, 0.009 OrgSe)	-29.8
Total Particulate (µg/g)	0.712 (0.490 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.690 (0.468 POrgSe, 0.125 PSeivvi, 0.096 PSe0)	-0.021 (0.021 POrgSe, 0 PSeivvi, 0 PSe0)	-3.0

Table 3-3
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to refinery dissolved selenium load reductions for the Oct. 30, 1999 transect.

Species	Base Case	No refinery	Change	% Change
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.080 (0.017 SeIV, 0.046 SeVI, 0.018 OrgSe)	-0.021 (0.004 SeIV, 0.012 SeVI, 0.005 OrgSe)	-20.8
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	0.846 (0.631 POrgSe, 0.131 PSeivvi, 0.083 PSe0)	-0.026 (0.026 POrgSe, 0 PSeivvi, 0 PSe0)	-3.0

Effects of Halving Refinery Loads

The effects of refinery loads were also evaluated by halving total selenium loads from refineries. Figure 3-12 through Figure 3-15 show the results of halving refinery loads for the simulation period of 1998-

2012. With this load change, selenite concentrations showed a decrease of 0.001 µg/L during low flow conditions. Selenate concentrations showed a decrease of 0.003 µg/L, and organic selenide showed a decrease of 0.002 µg/L. On a monthly average basis, selenite showed an average of 0.001 µg/L decrease for different months due to refinery increase (Figure 3-16). Selenate showed an average decrease of 0.006 µg/L for different months. Organic selenide showed average decrease of 0.002 µg/L. Particulate selenium as a result showed monthly average changes of 0.004 µg/g due to half refinery loads (Figure 3-17Figure 3-9). Selenium concentrations in clams showed a change of 0.08 µg/g (Figure 3-10). The model simulated Kd (expressed as particulate selenium in µg/g over total dissolved selenium in µg/L) showed large seasonal and inter-annual variations. Due to increase in dissolved selenium under half refinery loads and less significant changes in particulate selenium, simulated Kd values are higher under half refinery loads scenario.

The linkage between dissolved and particulate selenium was evaluated for the half refinery load scenario using the model at three locations: Suisun Bay, Carquinez Strait and San Pablo Bay for a dry period transect: Oct. 30, 1999.

At Suisun Bay, the model simulated total dissolved selenium concentration is 0.091 µg/L, of this 0.007 µg/L is contributed by half of refinery inputs (Table 3-4). The refinery contribution of dissolved selenium is dominated by selenate (0.003 µg/L), with a lower contribution from organic selenide and selenite (0.001 -0.002 µg/L). The dissolved selenium from refineries contributes up to 0.004 µg/g of particulate selenium in Suisun Bay due to uptake of dissolved selenium from refineries.

At Carquinez Strait, the model simulated total dissolved selenium concentration is 0.121 µg/L, of this 0.018 µg/L is contributed by half of refinery inputs (Table 3-5). The refinery contribution of dissolved selenium is dominated by selenate (0.005 µg/L), with a lower contribution from organic selenide and selenite (0.003 -0.005 µg/L). This contributes up to 0.016 µg/g of particulate selenium in Carquinez Strait due to the uptake of dissolved selenium from refineries.

At San Pablo Bay, the model-simulated total dissolved selenium concentration is 0.101 µg/L, of this 0.01 µg/L is contributed by half of refinery inputs (Table 3-6). The refinery contribution of dissolved selenium is dominated by selenate (0.006µg/L), with the contribution from organic selenide and selenite at 0.004 - 0.0025 µg/L. This contributes up to 0.017 µg/g of particulate selenium in San Pablo Bay due to uptake.

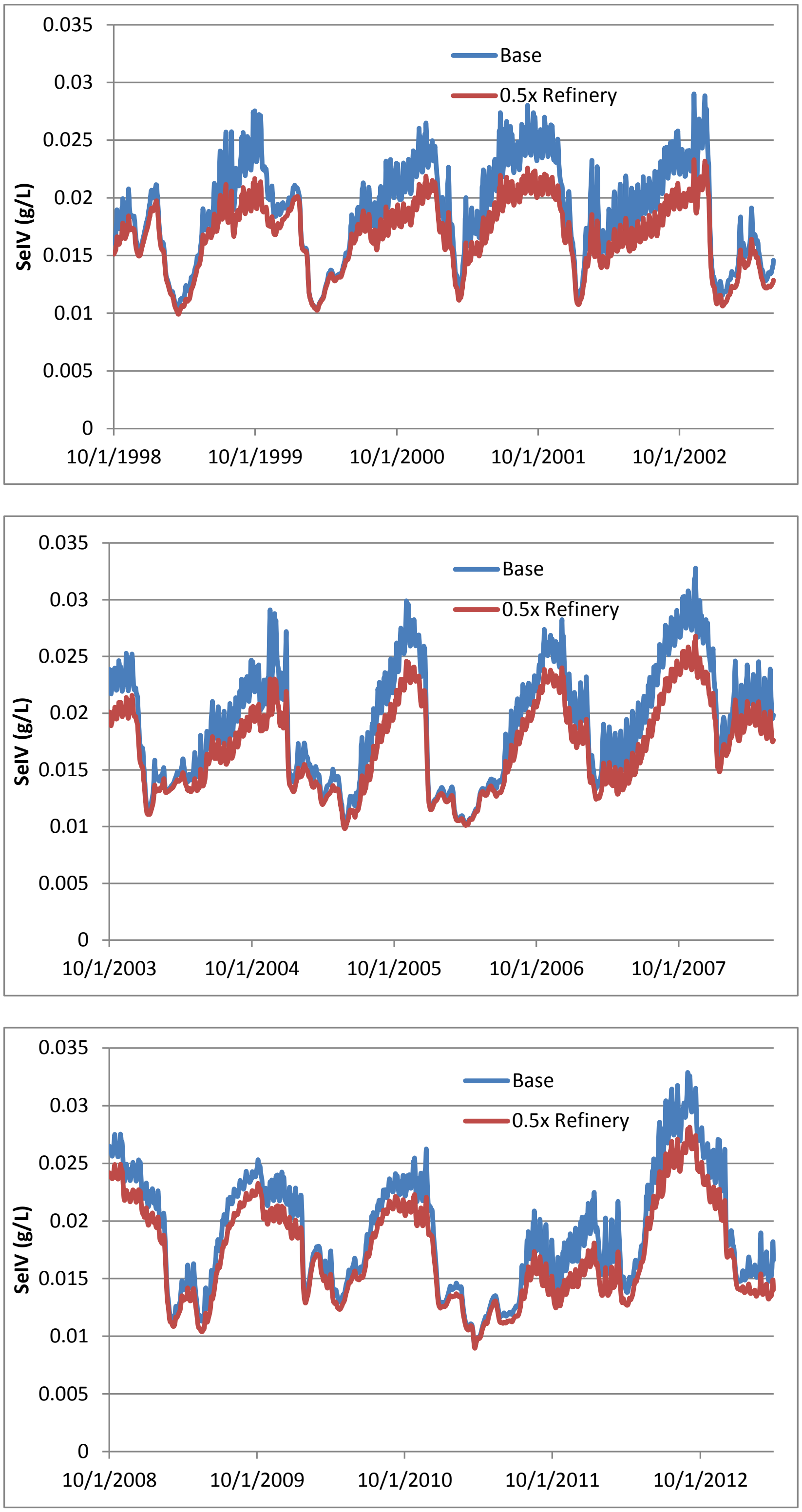


Figure 3-12
Simulated concentrations of selenite under current conditions and half refinery scenario at Carquinez Strait.

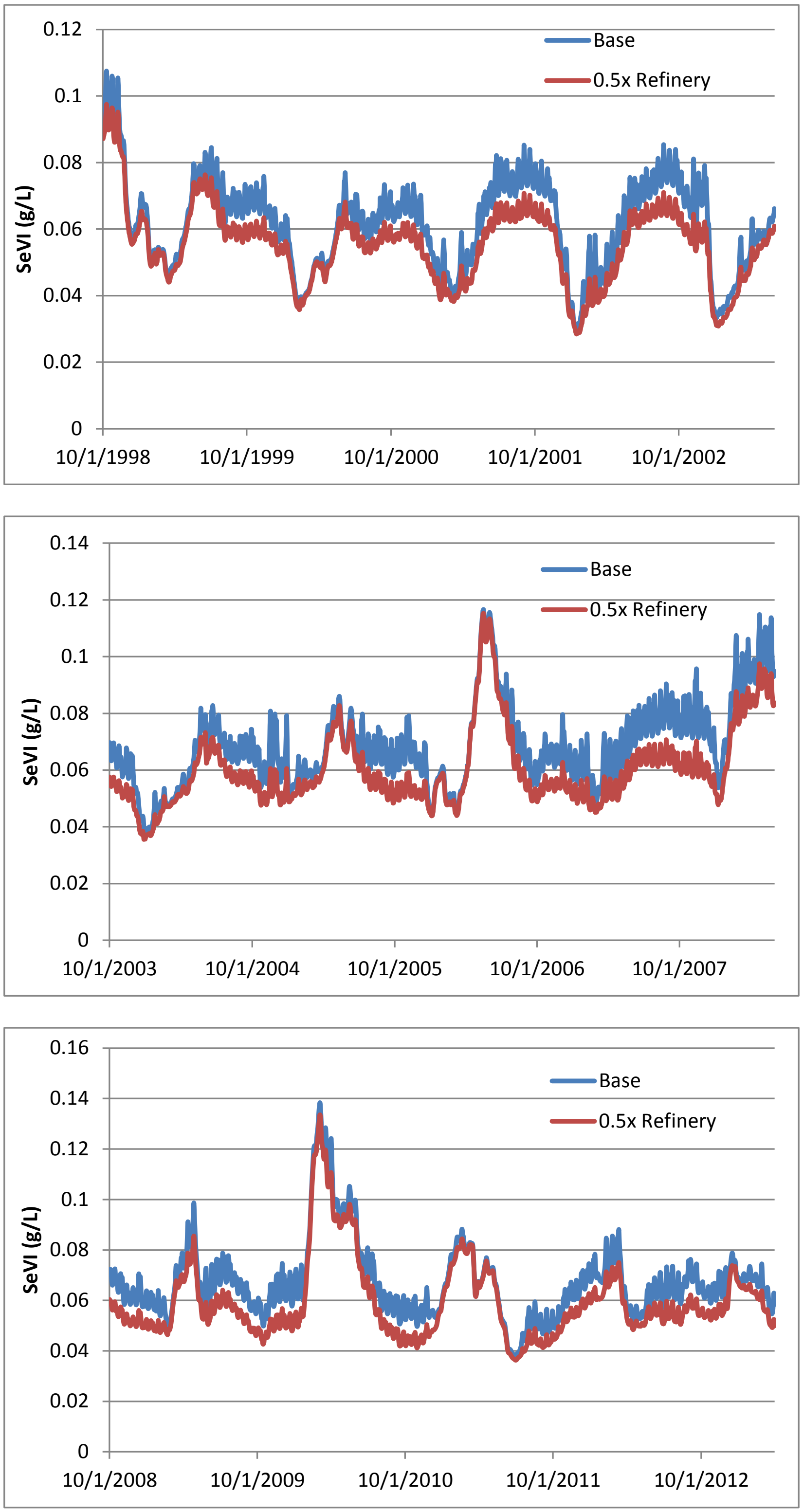


Figure 3-13
Simulated concentrations of selenate under current conditions and half refinery scenario at Carquinez Strait.

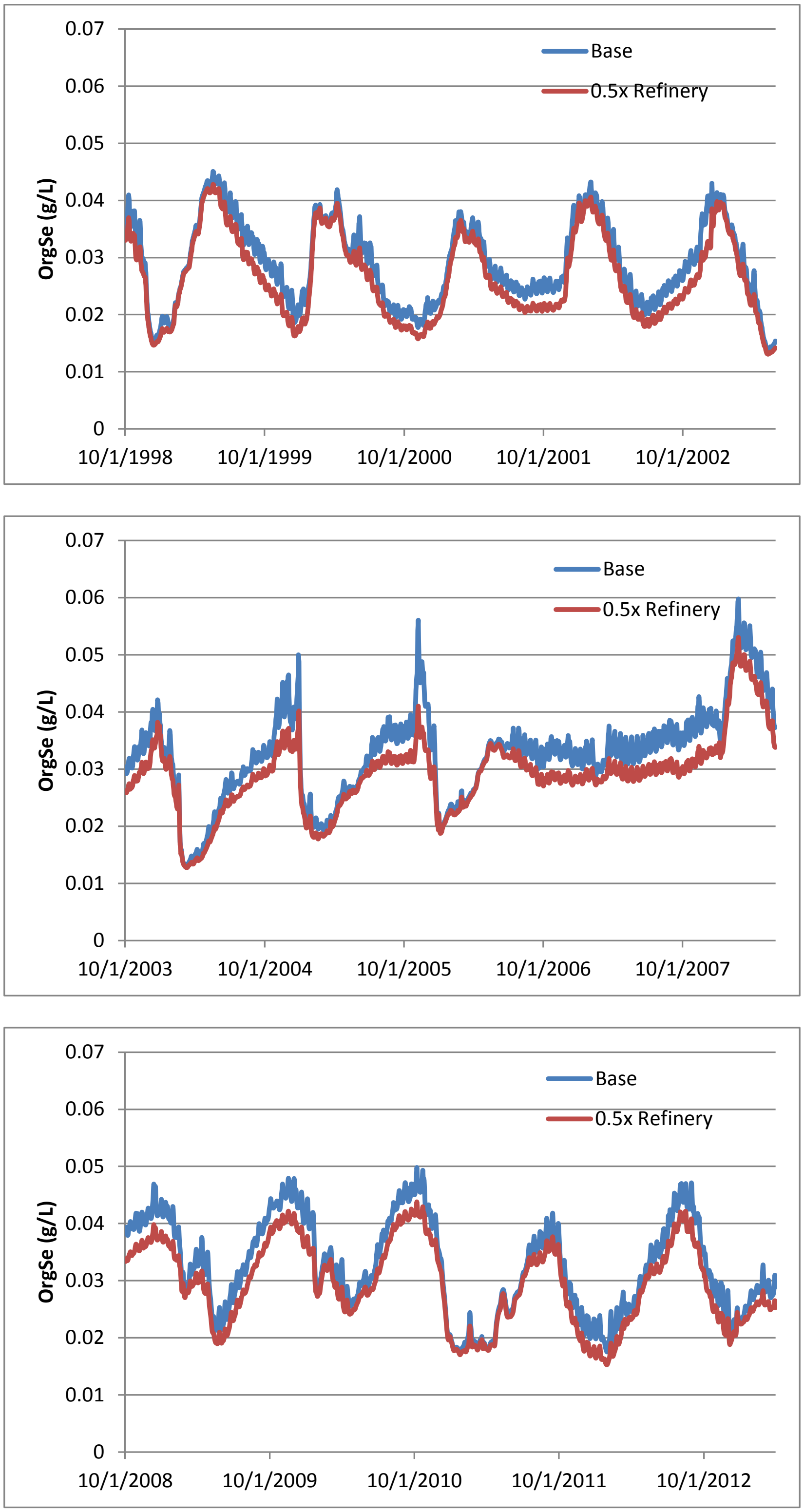


Figure 3-14
Simulated concentrations of organic selenide under current conditions and half refinery scenario at Carquinez Strait.

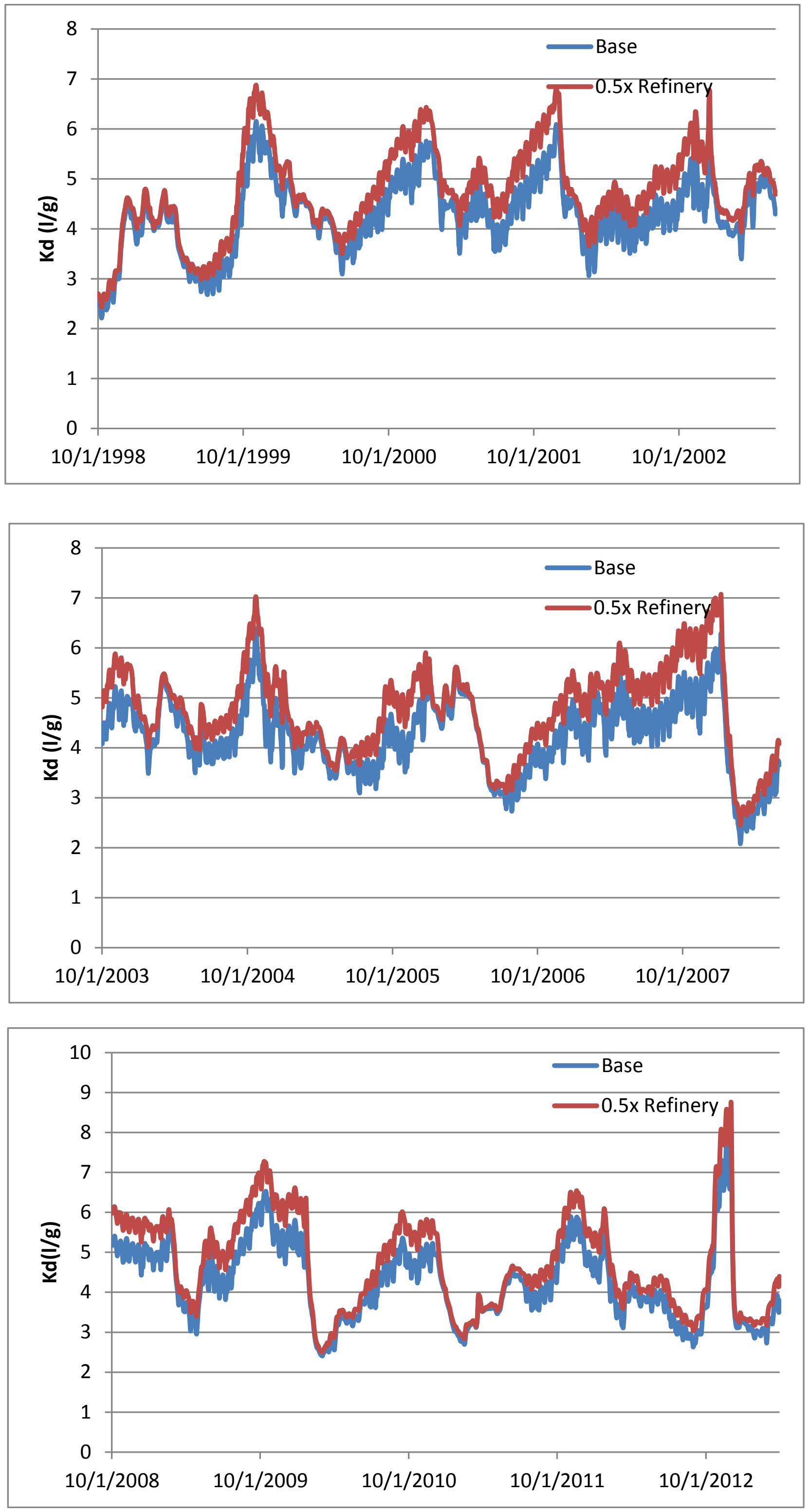


Figure 3-15
Simulated Kd under current conditions and half refinery scenario at Carquinez Strait.

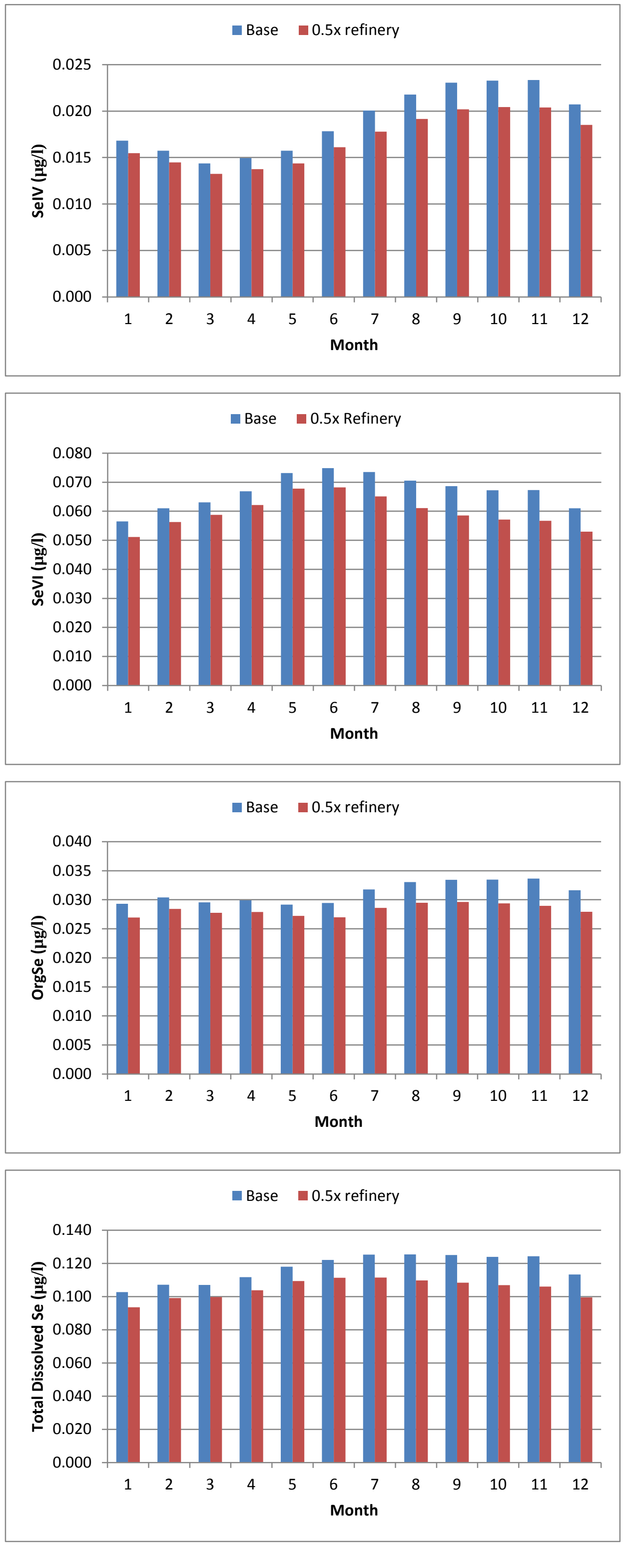


Figure 3-16
Simulated concentrations of dissolved selenium under current conditions and half refinery scenario at Carquinez Strait.

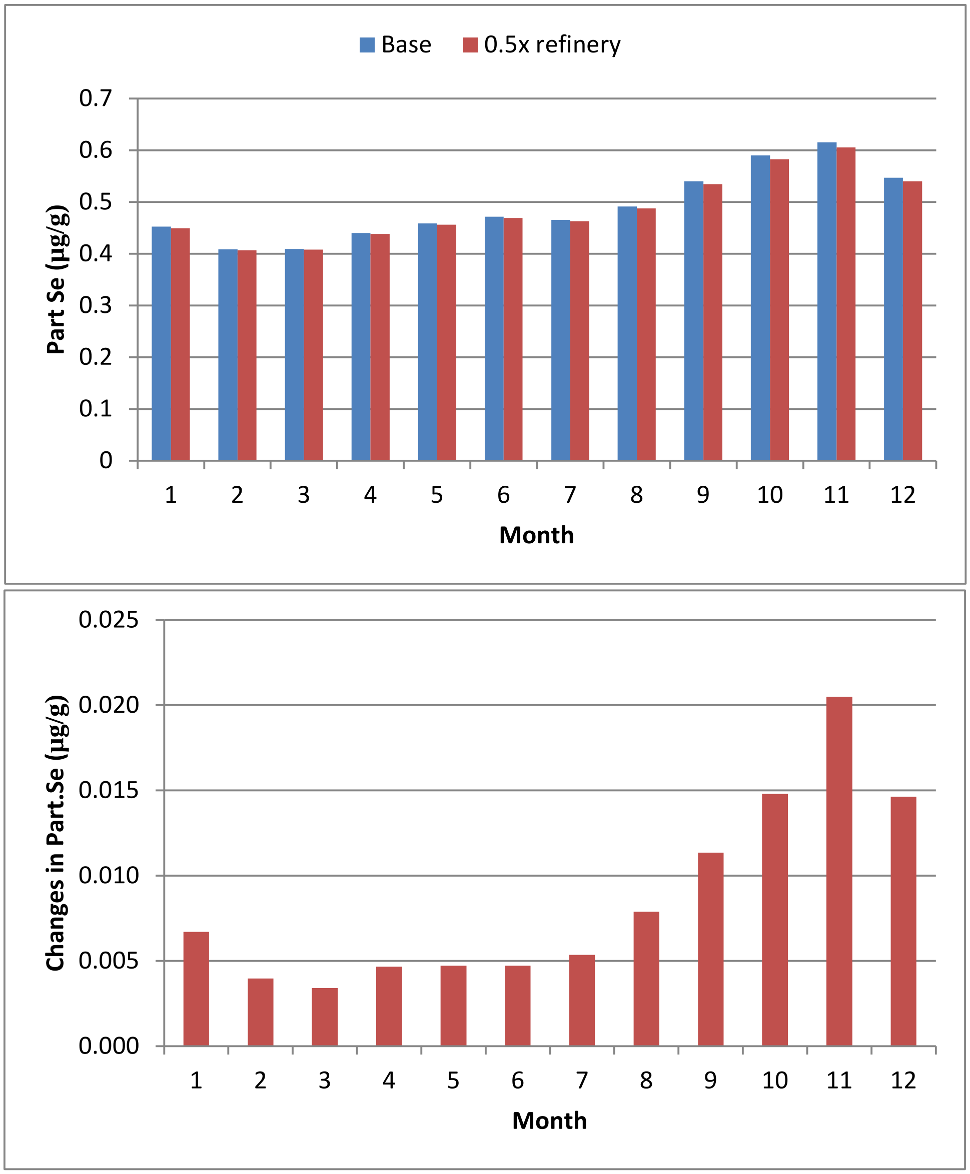


Figure 3-17
Simulated changes in particulate selenium due to half refinery loads at Carquinez Strait.

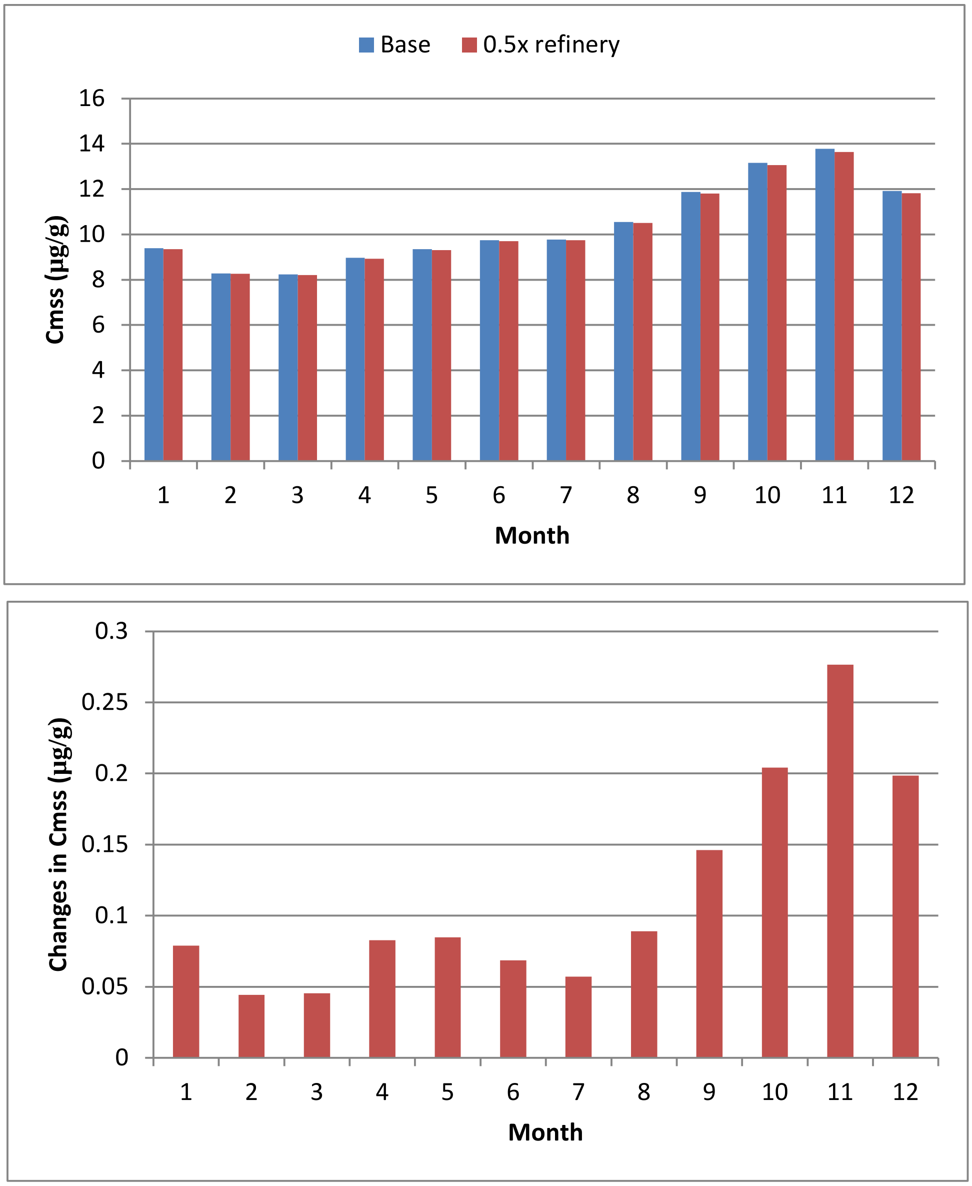


Figure 3-18
Simulated changes in clam selenium concentrations due to half refinery loads at Carquinez Strait.

Table 3-4
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to half refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Half refinery	Change
Total Dissolved	0.091 (0.014 SeIV, 0.057 SeVI, 0.02 OrgSe)	0.084 (0.012 SeIV, 0.054 SeVI, 0.018 OrgSe)	0.007 (0.001 SeIV, 0.003 SeVI, 0.002 OrgSe)
Total Particulate (µg/g)	0.563 (0.328 POrgSe, 0.118 PSeivvi, 0118 PSe0)	0.559 (0.326 POrgSe, 0.117 PSeivvi, 0.117 PSe0)	0.004 (0.002POrgSe, 0.001 PSeivvi, 0.001 PSe0)

Table 3-5
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to half refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Half refinery	Change
Total Dissolved	0.121 (0.022 SeIV, 0.07 SeVI, 0.03 OrgSe)	0.103 (0.019 SeIV, 0.06 SeVI, 0.024 OrgSe)	0.018 (0.003 SeIV, 0.01 SeVI, 0.005 OrgSe)
Total Particulate (µg/g)	0.712 (0.490 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.696 (0.479 POrgSe, 0.124 PSeivvi, 0.092 PSe0)	0.016 (0.011 POrgSe, 0.001 PSeivvi, 0.004 PSe0)

Table 3-6
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to half refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Half refinery	Change
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.091 (0.0191 SeIV, 0.052 SeVI, 0.020 OrgSe)	0.010 (0.002 SeIV, 0.006 SeVI, 0.002OrgSe)
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	0.855 (0.645 POrgSe, 0.130PSeivvi, 0.080 PSe0)	0.035 (0.013 POrgSe, 0.002 PSeivvi, 0.003 PSe0)

Effects of Riverine Load Reductions

The effects of riverine load reductions were evaluated by reducing dissolved selenium loads from riverine sources (Sacramento and San Joaquin Rivers) to zero. Particulate selenium loads from riverine sources remained unchanged.

Figure 3-19– Figure 3-21 show the results of reducing riverine loads to zero for the simulation period of 1998-2012. Without riverine inputs, selenite concentrations showed a reduction of 0.005-0.010 µg/L. Selenate concentrations showed a reduction of 0.02- 0.03 µg/L, and organic selenide showed a reduction of 0.03 µg/L. Without riverine inputs, particulate organic selenide and particulate selenite and selenate both showed some decrease (Figure 3-22 and Figure 3-23). As in the previous scenario with no refinery loads, due to decreases in dissolved selenium under for no riverine loads and smaller changes in particulate selenium, simulated Kd values are higher (Figure 3-25).

Overall, both particulate selenium and selenium concentrations in clams showed some decrease without the riverine inputs (Figure 3-24 and Figure 3-26). On average, selenite showed 0.005-0.007 µg/L decrease in different months due to the riverine load reduction. Selenate showed a decrease of 0.025 – 0.04 µg/L for different months due to this load reduction. Organic selenide showed a decrease of 0.01 – 0.015 µg/L throughout the year (Figure 3-27). Particulate selenium showed a decrease in particulate organic selenide and particulate selenite and seleante (Figure 3-28). On average, particulate selenium showed an average of 0.02 – 0.06 µg/g changes due to riverine inputs (Figure 3-29). The changes in particulate selenium are largest during May. The predicted change in particulate selenium in November averages 0.025 µg/g. Selenium concentrations in clams showed a change of 0.4 to 1.6 µg/g for different months (Figure 3-30).

The linkage between dissolved and particulate selenium was evaluated for the no riverine input scenario using the model at three locations: Suisun Bay, Carquinez Strait and San Pablo Bay for a dry period transect, Oct. 30, 1999.

For an earlier transect on Oct.30, 1999, model simulated total dissolved selenium concentration in Suisun Bay is at 0.091 µg/L, of this 0.051 µg/L is contributed by riverine inputs (Table 3-7). The riverine contribution of dissolved selenium is dominated by selenate (0.036 µg/L), with a lower contribution from organic selenide and selenite (0.006 -0.009 µg/L). The dissolved selenium from riverine inputs contributes up to 0.011 µg/g of particulate selenium in Suisun Bay due to uptake of dissolved selenium from riverine inputs.

The model simulated total dissolved selenium concentration in Carquinez Strait is 0.121 µg/L, of this 0.026 µg/L is contributed by riverine inputs (Table 3-8). The riverine contribution of dissolved selenium is dominated by selenate (0.017 µg/L), with a lower contribution from organic selenide and selenite (0.003 -0.006 µg/L). This dissolved selenium from riverine inputs contributes up to 0.023 µg/g of particulate selenium in Carquinez Strait due to uptake of dissolved selenium from riverine inputs.

For Oct.30, 1999, model simulated total dissolved selenium concentration in San Pablo Bay is 0.101 µg/L, with 0.014 µg/L contributed by riverine inputs (Table 3-9). The riverine contribution of dissolved selenium is dominated by selenate (0.009 µg/L), with smaller contributions from organic selenide and selenite (0.002 - 0.003 µg/L). This dissolved selenium from riverine contributes up to 0.024 µg/g of particulate selenium in San Pablo Bay due to uptake.

The results show that without riverine dissolved selenium inputs, simulated particulate selenium concentrations in the Bay could decrease by up to 0.023 µg/g (Table 3-8). Without the riverine dissolved selenium inputs, the decrease in dissolved selenium concentrations in the Bay is significant, and mostly associated with selenate. Because selenate uptake rates are lower, a smaller change in particulate selenium is predicted.

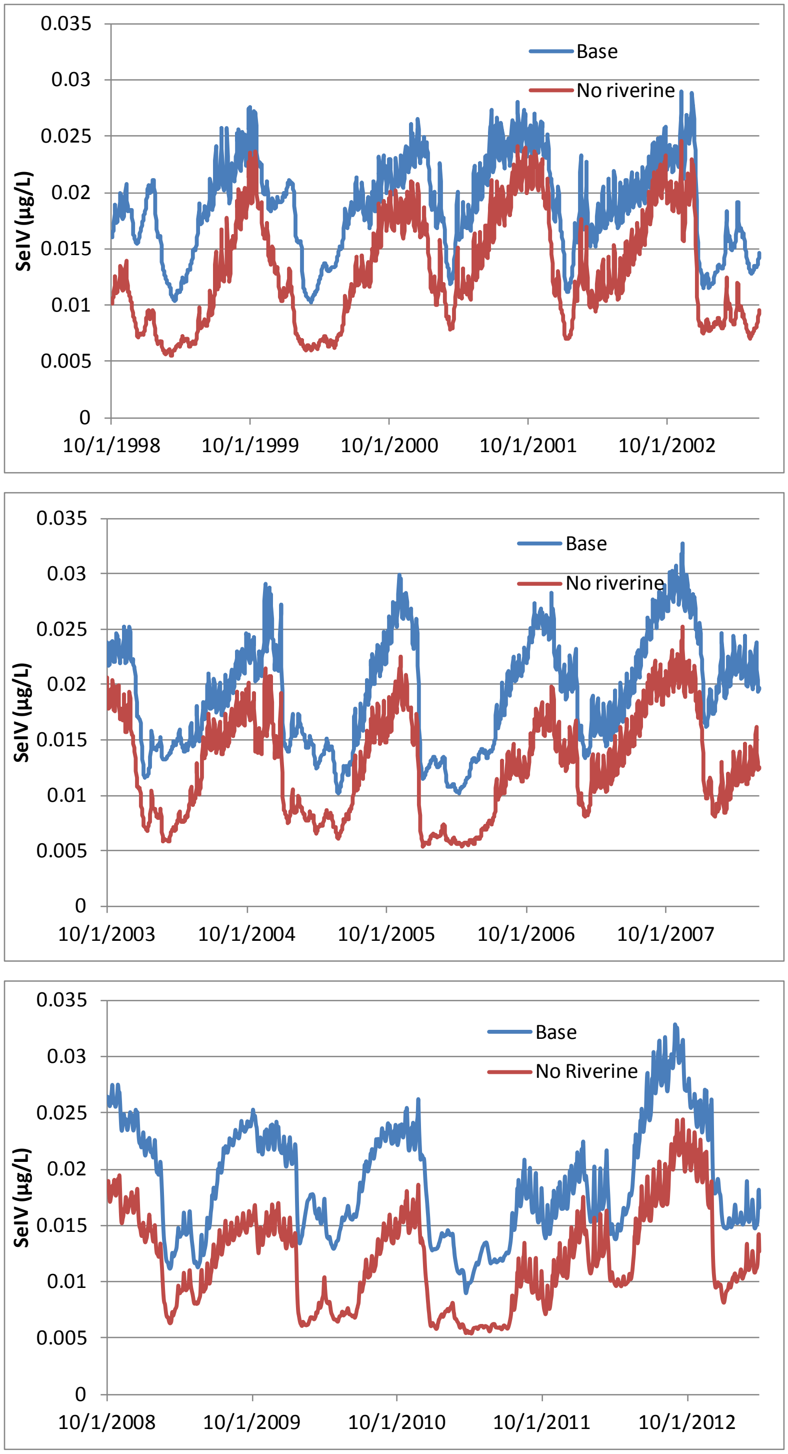


Figure 3-19
Simulated concentrations of selenite under current conditions and no riverine load scenario at Carquinez Strait.

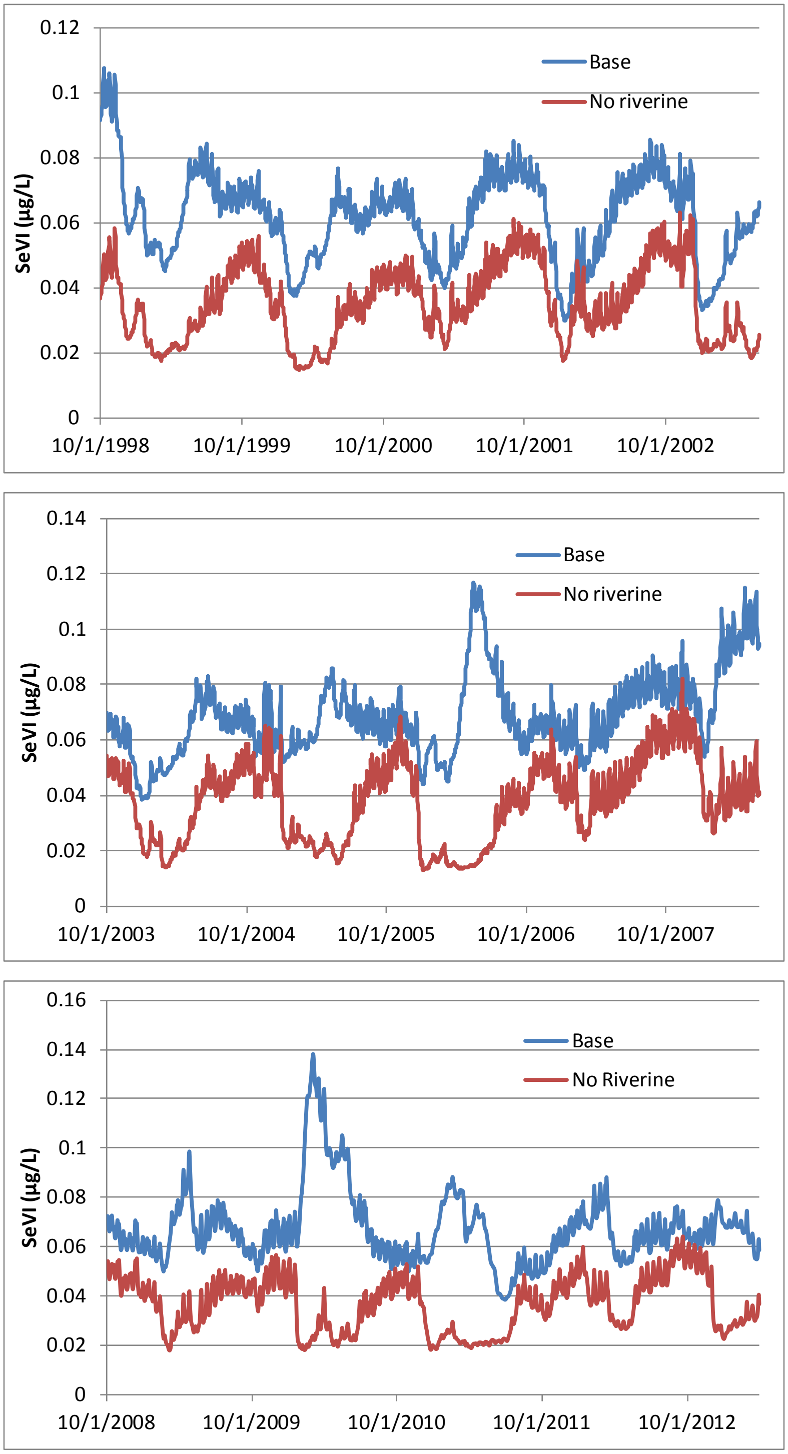


Figure 3-20
Simulated concentrations of selenate under current conditions and no riverine load scenario at Carquinez Strait.

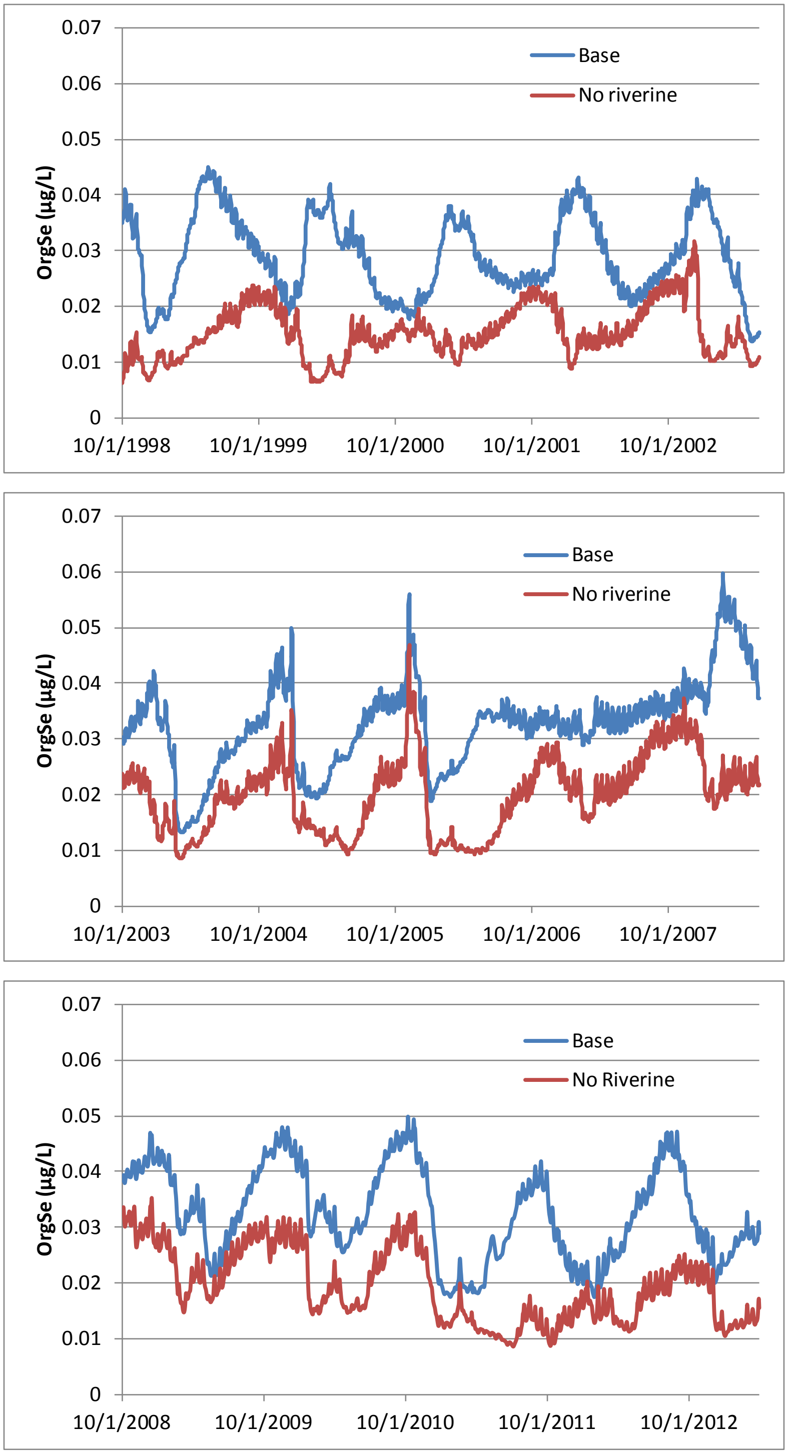


Figure 3-21
Simulated concentrations of organic selenide under current conditions and no riverine load scenario at Carquinez Strait.

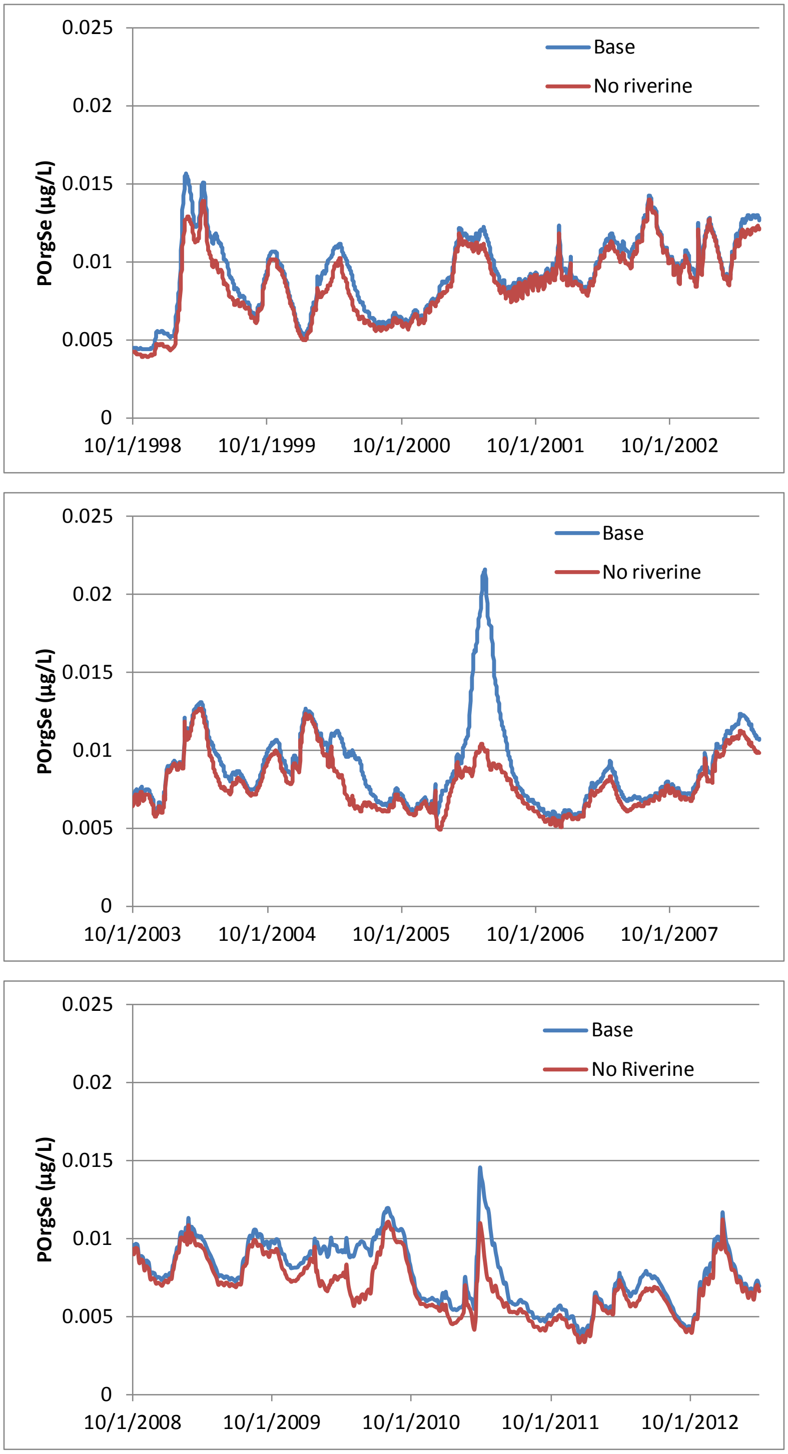


Figure 3-22
Simulated concentrations of particulate organic selenide under current conditions and no riverine load scenario at Carquinez Strait.

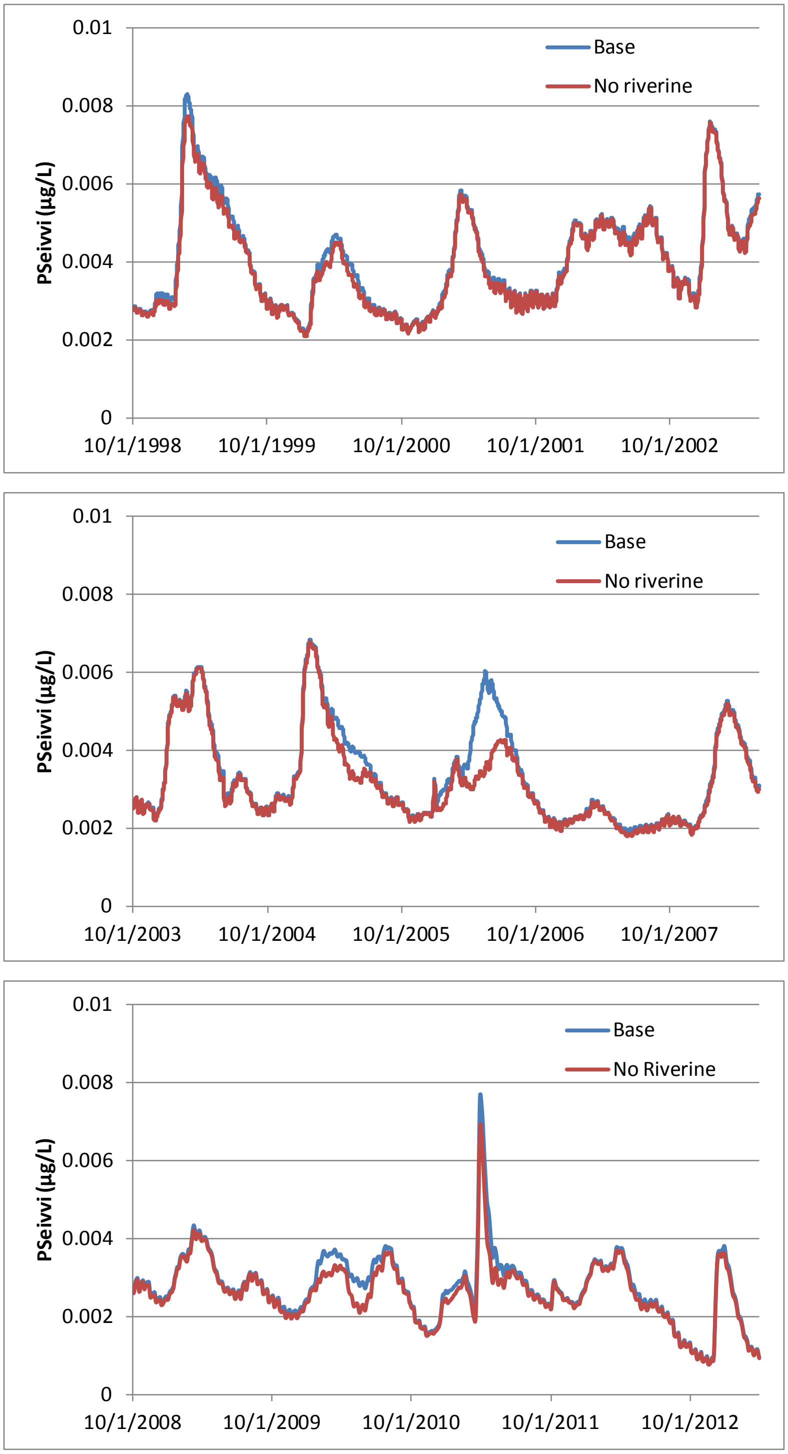


Figure 3-23
Simulated concentrations of particulate selenite and selenate under current conditions and no riverine load scenario at Carquinez Strait.

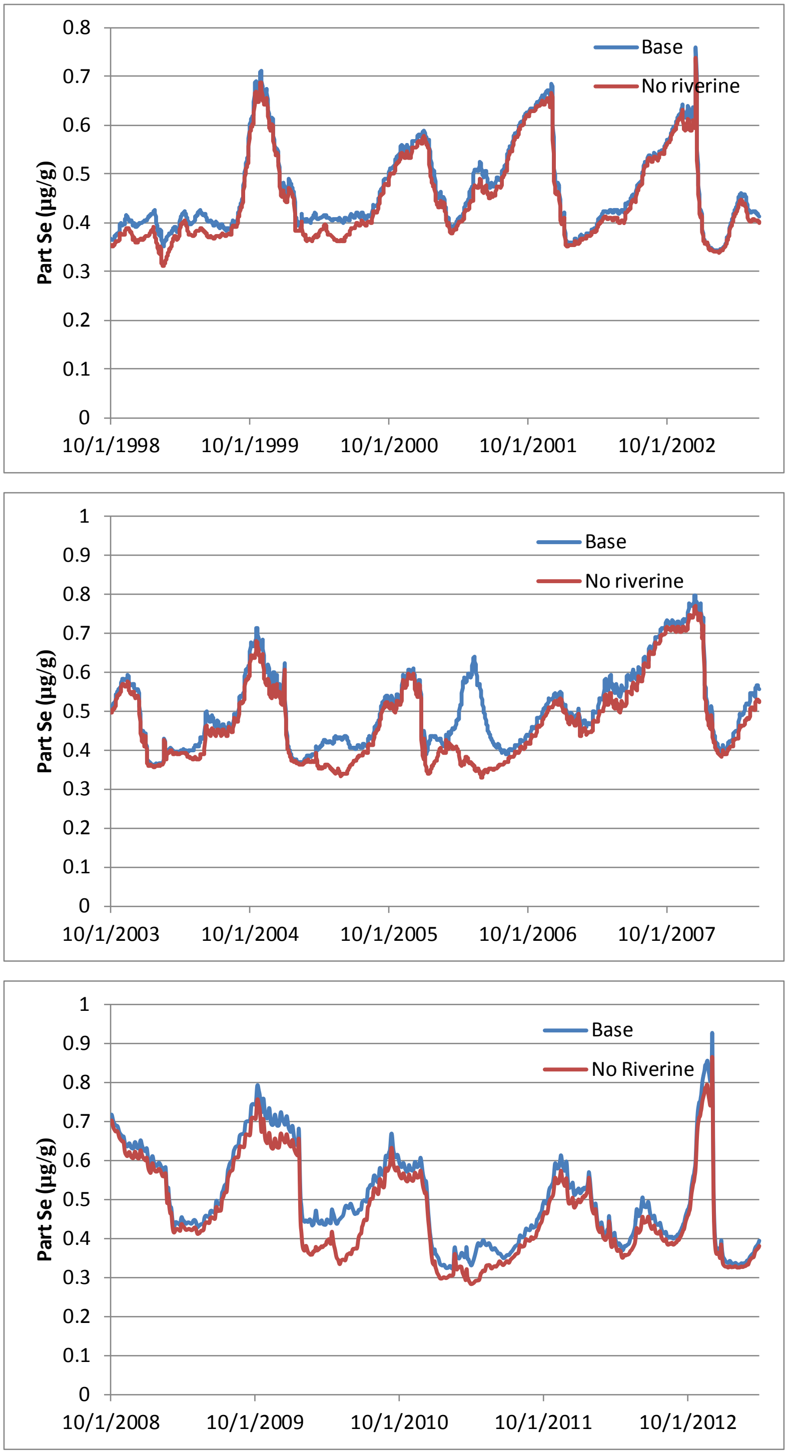


Figure 3-24
Simulated concentrations of particulate selenium under current conditions and no riverine load scenario at Carquinez Strait.

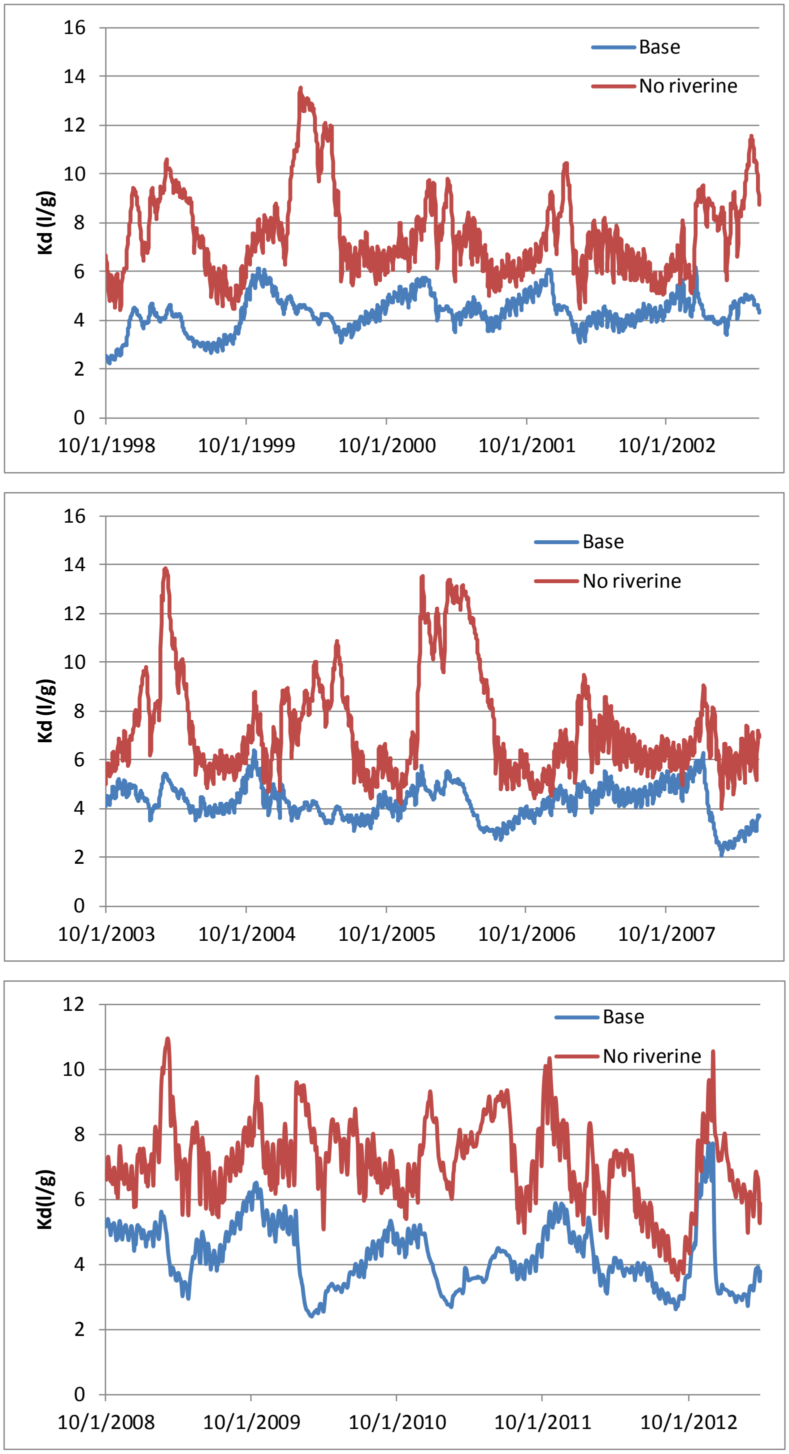


Figure 3-25
Simulated Kds under current conditions and no riverine scenario at Carquinez Strait.

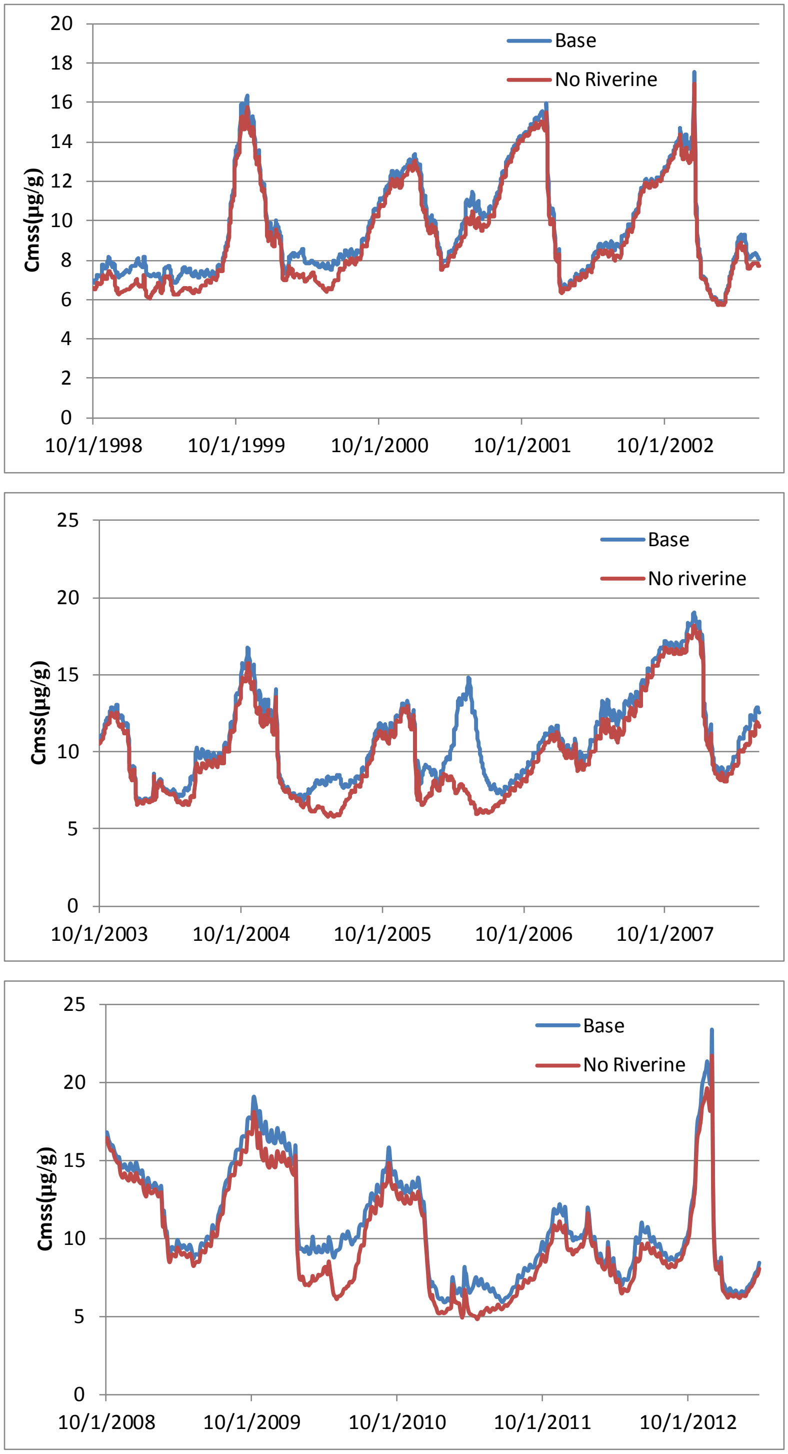


Figure 3-26
Simulated concentrations of selenium in clams under current conditions and no riverine load scenario at Carquinez Strait.

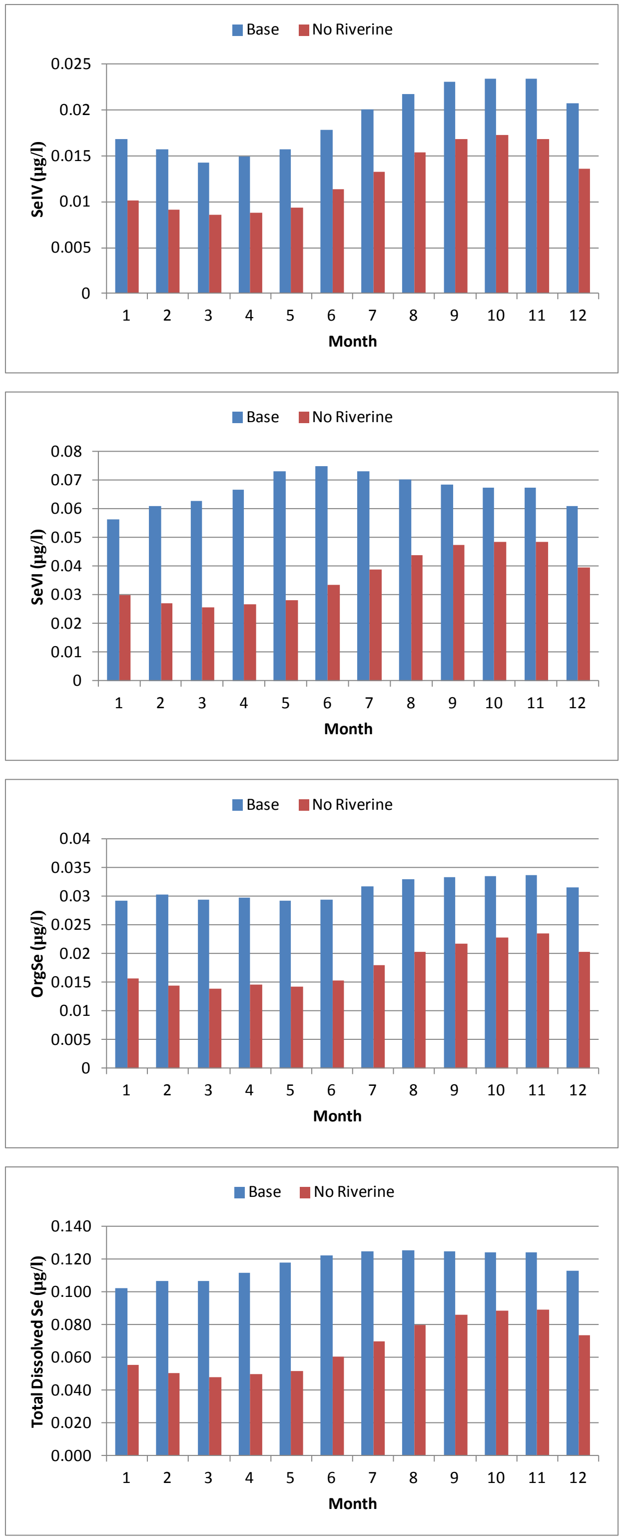


Figure 3-27
Simulated concentrations of dissolved selenium under current conditions and no riverine load scenario at Carquinez Strait.

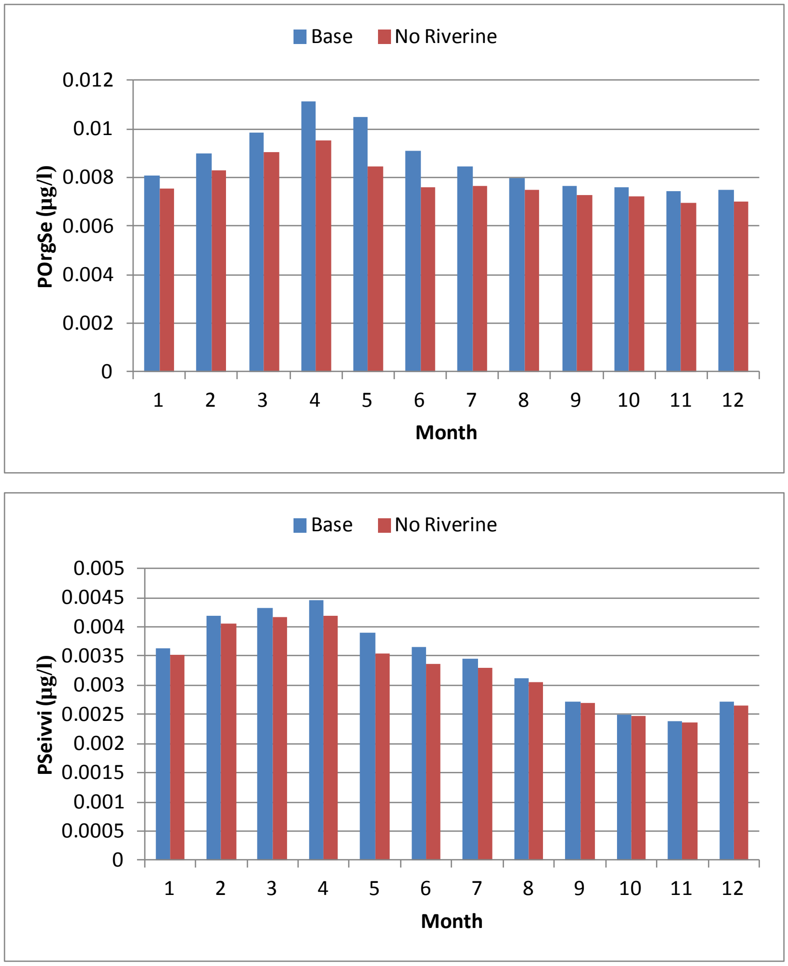
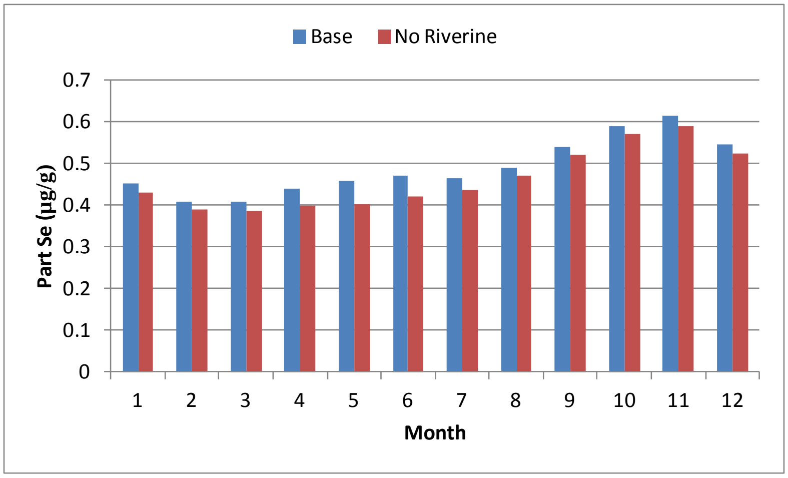


Figure 3-28
Simulated changes in particulate organic selenide and particulate selenite and selenate due to riverine load reductions to zero at Carquinez Strait.



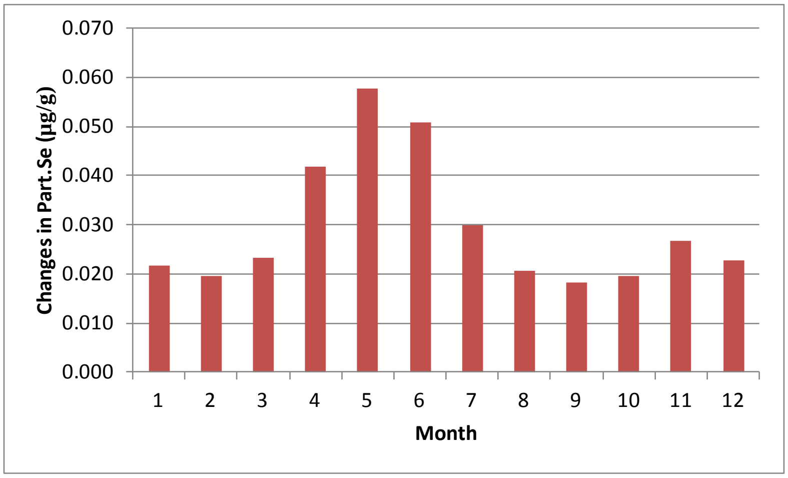


Figure 3-29
Simulated changes in particulate selenium due to riverine load reductions to zero at Carquinez Strait.

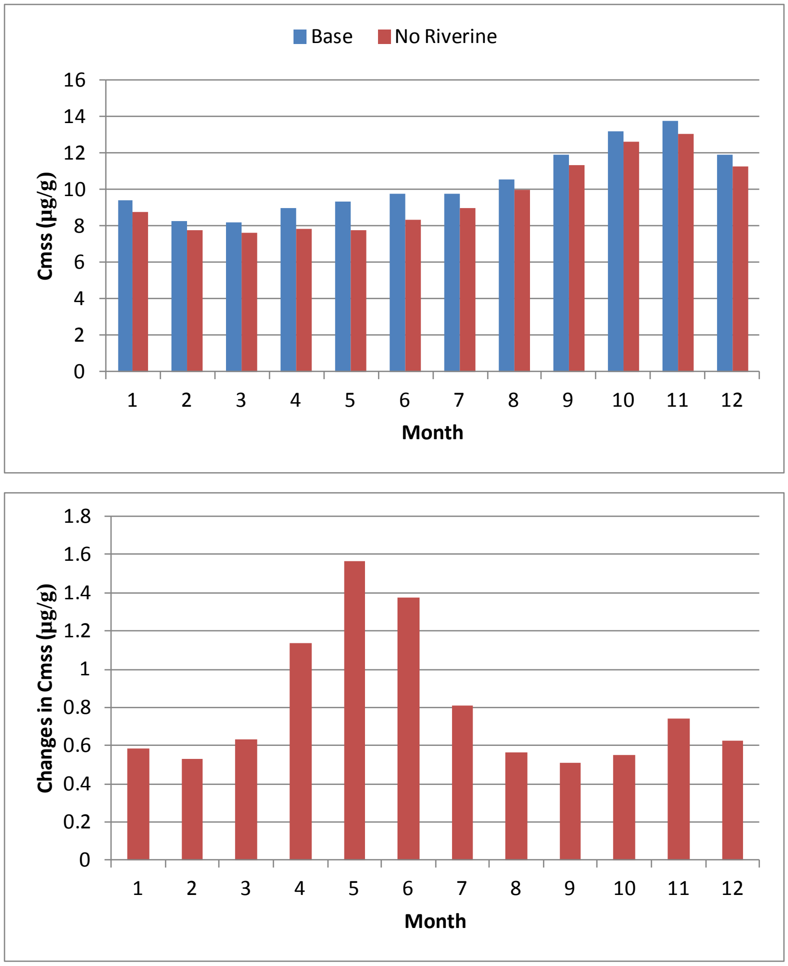


Figure 3-30
Simulated changes in clam selenium concentrations due to riverine load reductions at Carquinez Strait.

Table 3-7
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to riverine dissolved selenium loads reductions to zero for Oct. 30, 1999 transect.

Species	Base Case	No riverine inputs	Change	% Change
Total Dissolved	0.091 (0.014 SeIV, 0.057 SeVI, 0.02 OrgSe)	0.040 (0.008 SeIV, 0.02 SeVI, 0.01 OrgSe)	-0.051 (0.006 SeIV, 0.036 SeVI, 0.009OrgSe)	-56.0
Total Particulate (µg/g)	0.563 (0.328 POrgSe, 0.118 PSeivvi, 0.118 PSe0)	0.553 (0.318 POrgSe, 0.118 PSeivvi, 0.117 PSe0)	-0.011 (0.01 POrgSe, 0 PSeivvi, 0.001 PSe0)	-2.0

Table 3-8
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to riverine dissolved selenium loads reductions to zero for Oct. 30, 1999 transect.

Species	Base Case	No riverine inputs	Change	% Change
Total Dissolved	0.121 (0.02 SeIV, 0.07 SeVI, 0.03 OrgSe)	0.095 (0.02 SeIV, 0.05 SeVI, 0.02 OrgSe)	-0.026 (0.003 SeIV, 0.017 SeVI, 0.006 OrgSe)	-21.5
Total Particulate (µg/g)	0.712 (0.49 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.689 (0.467 POrgSe, 0.125 PSeivvi, 0.096 PSe0)	-0.023 (0.023 POrgSe, 0 PSeivvi, 0 PSe0)	-3.2

Table 3-9
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to riverine dissolved selenium loads reductions to zero for Oct. 30, 1999 transect.

Species	Base Case	No riverine inputs	Change	% Change
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.02 OrgSe)	0.087 (0.02 SeIV, 0.05 SeVI, 0.02 OrgSe)	-0.014 (0.002 SeIV, 0.009 SeVI, 0.003 OrgSe)	-13.9
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	0.848 (0.634 POrgSe, 0.131 PSeivvi, 0.083 PSe0)	-0.024 (0.024 POrgSe, 0.001 PSeivvi, 0 PSe0)	-2.8

Effects of Refinery, Riverine and Local Tributary Input Reductions

The effects of the major loads were evaluated by reducing dissolved selenium loads from riverine (Sacramento and San Joaquin Rivers), refineries, other point sources, and tributaries to zero. The refinery, other point sources, and tributary loads are termed the local loads for this discussion. Particulate selenium loads from all the above sources remained unchanged.

Figure 3-31– Figure 3-33 show results of reducing riverine and local loads to zero for the simulation period of 1998-2012. Without riverine and local inputs, selenite concentrations showed a reduction of 0.005-0.015 µg/L. Selenate concentrations showed a reduction of 0.02-0.04µg/L, and organic selenide showed a reduction of 0.03 µg/L. Without riverine and local inputs, particulate organic selenide and particulate selenite and selenate both showed some decreases (Figure 3-34 and Figure 3-35). However, the reduction in dissolved selenium and smaller changes in particulate selenium leads to a much higher estimate of Kd for this scenario compared to the base case (Figure 3-37).

Overall, both particulate selenium and selenium concentrations in clams showed some decrease without the riverine and local inputs (Figure 3-36 and Figure 3-38). On average, selenite showed a 0.005- 0.012 µg/L decrease, and selenate showed a decrease of 0.035 – 0.055 µg/L for different months due to the load reduction. Organic selenide showed a decrease of 0.02 µg/L throughout the year (Figure 3-39). Overall total dissolved selenium showed a decrease of 0.065- 0.08 µg/L. Particulate selenium species showed a decrease in particulate organic selenide and particulate selenite and selenate (Figure 3-40). On average, particulate selenium showed an average of 0.02 – 0.06 µg/g changes due to the curtailment of riverine and local inputs (Figure 3-41). The changes in particulate selenium are largest during May. Selenium concentrations in clams showed a change of 0.6 to 1.7 µg/g changes for different months (Figure 3-42).

As in the previous section, the linkage between dissolved and particulate selenium was evaluated for the no riverine and local load scenario using the model at three locations: Suisun Bay, Carquinez Strait and San Pablo Bay for a dry period transect, Oct. 30, 1999.

The model simulated total dissolved selenium concentration in Suisun Bay is 0.091 µg/L, with 0.064 µg/L is contributed by riverine and local inputs (Table 3-10). The contribution of dissolved selenium is dominated by selenate (0.043 µg/L), with lower contributions from organic selenide and selenite (0.009 -0.013 µg/L). This dissolved selenium from riverine and local loads contributes up to 0.016 µg/g of particulate selenium at this location.

The total dissolved selenium concentration in Carquinez Strait is 0.121 µg/L, with 0.062 µg/L contributed by riverine and local inputs (Table 3-11). The contribution of dissolved selenium is dominated by selenate (0.037 µg/L), with lower contributions from organic selenide and selenite (0.007 -0.016 µg/L). This dissolved selenium from riverine and local loads contributes up to 0.045 µg/g of particulate selenium in Carquinez Strait.

At San Pablo Bay, the total dissolved selenium concentration is 0.101 µg/L, with 0.035µg/L is contributed by riverine and local inputs (Table 3-12). The contribution of dissolved selenium is dominated by selenate (0.021 µg/L), with less contribution from organic selenide and selenite (0.006 -0.008 µg/L). This dissolved selenium from riverine and local contributes up to 0.051 µg/g of particulate selenium in Carquinez Strait due to uptake of dissolved selenium from riverine and local inputs.

The results suggested without riverine and local dissolved selenium inputs, simulated particulate selenium concentrations in the Bay could decrease by up to 0.045 µg/g (Table 3-11).

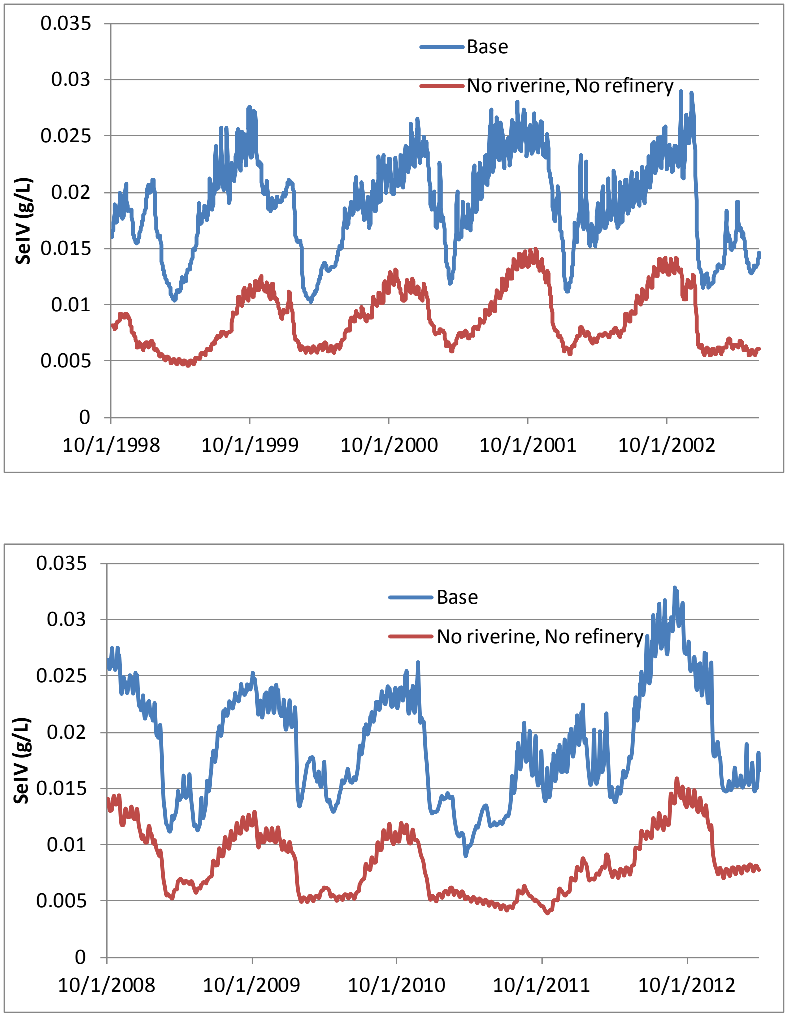


Figure 3-31
Simulated concentrations of selenite under current conditions and no riverine and local inputs at Carquinez Strait.

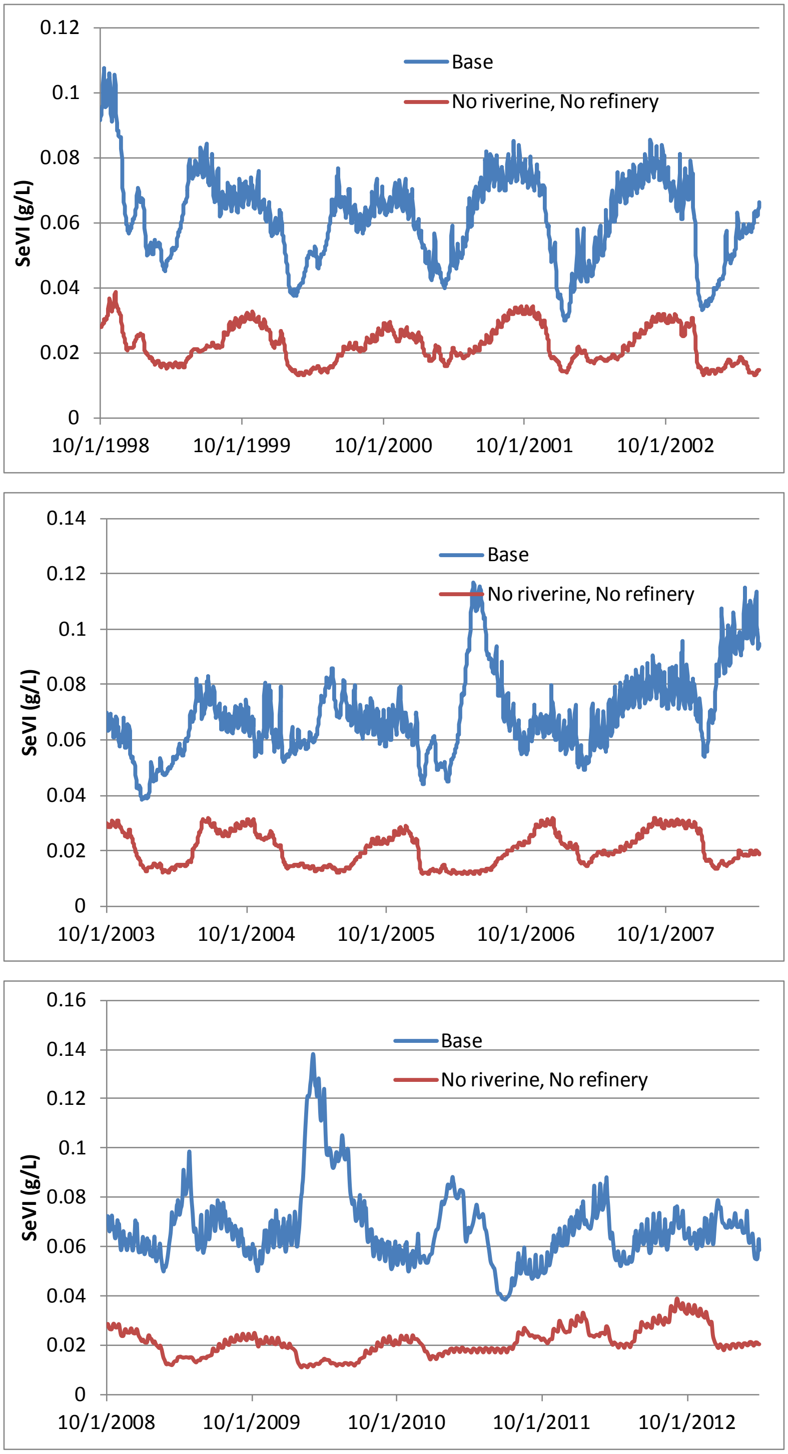


Figure 3-32
Simulated concentrations of selenate under current conditions and no riverine and local inputs at Carquinez Strait.

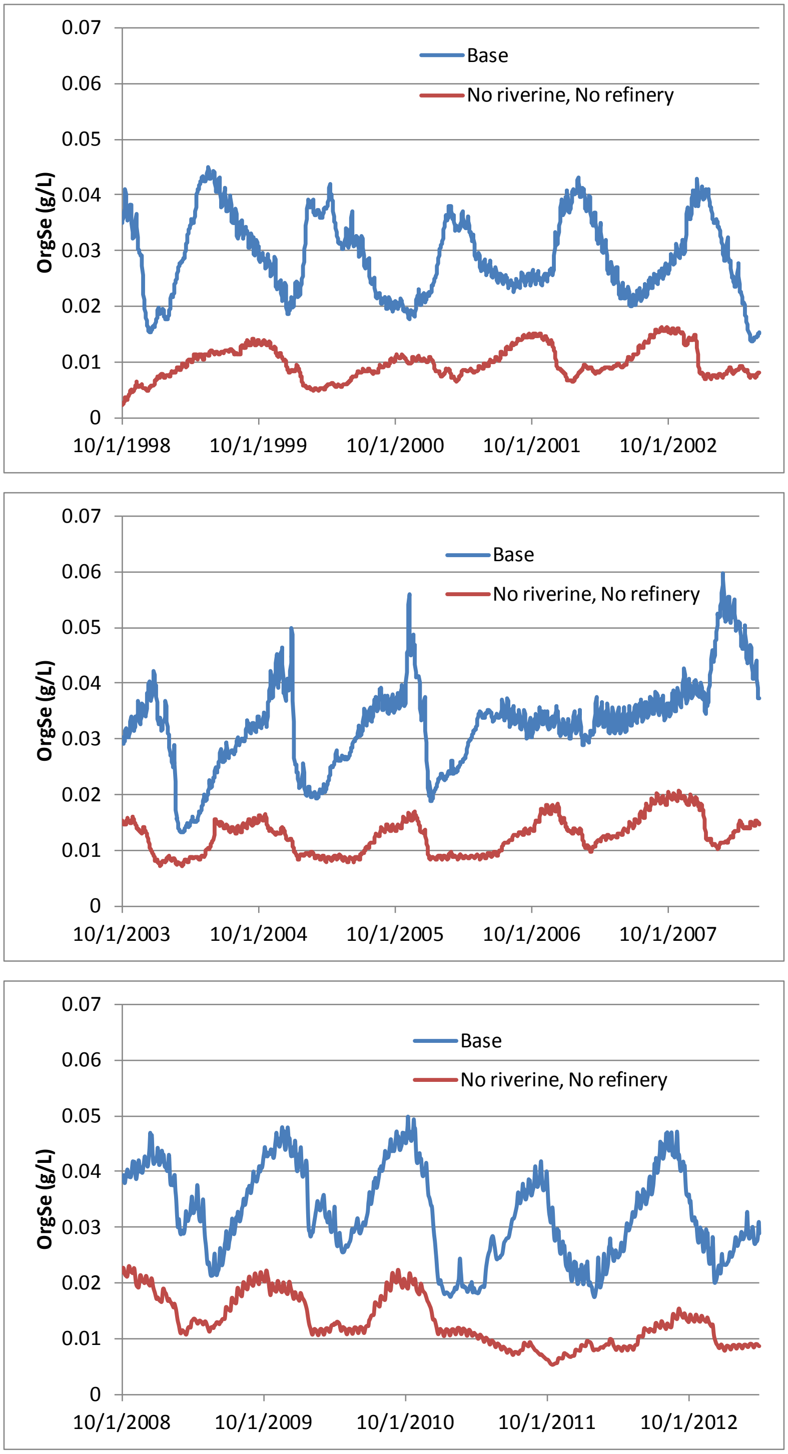


Figure 3-33
Simulated concentrations of organic selenide under current conditions and no riverine and local inputs at Carquinez Strait.

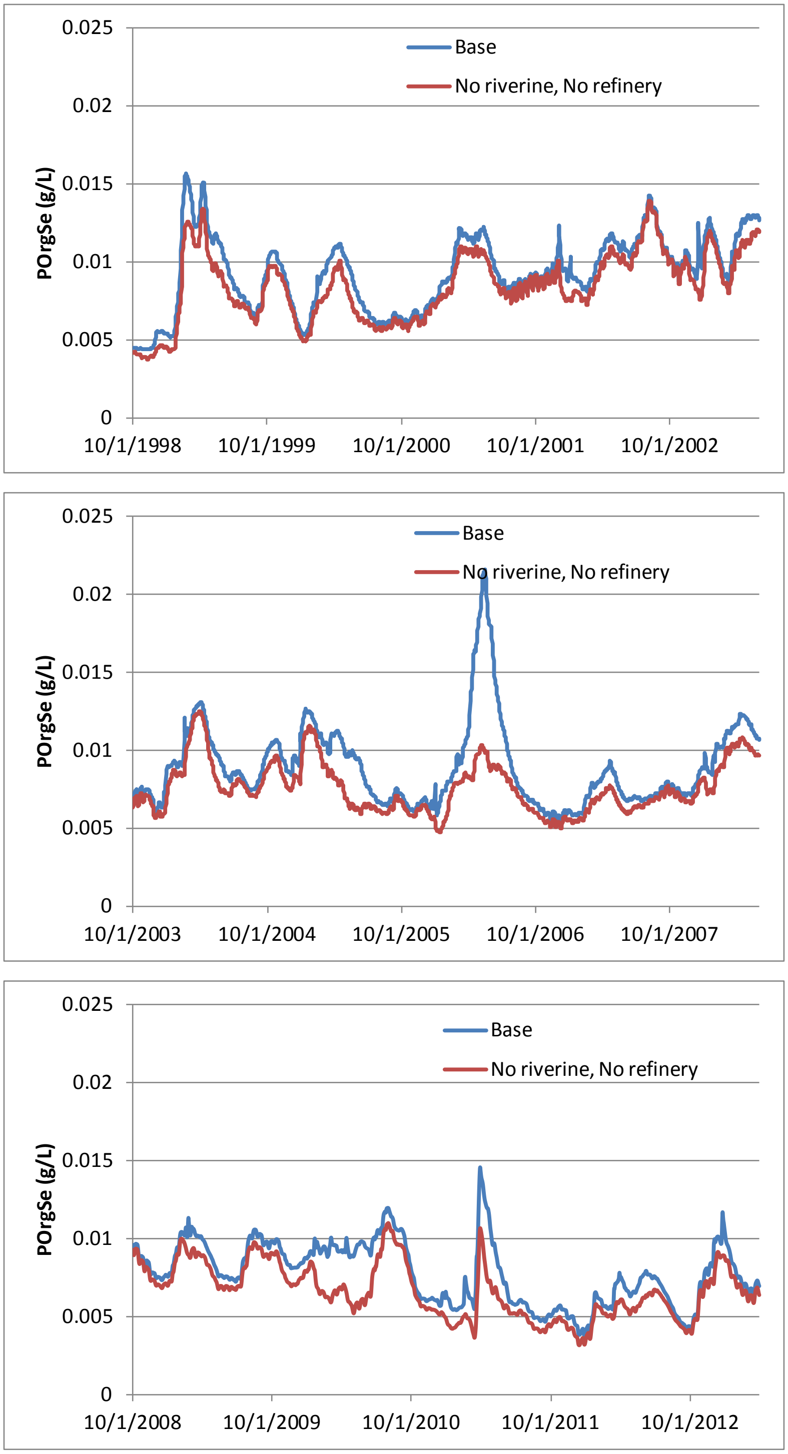


Figure 3-34
Simulated concentrations of particulate organic selenide under current conditions and no riverine and local inputs at Carquinez Strait.

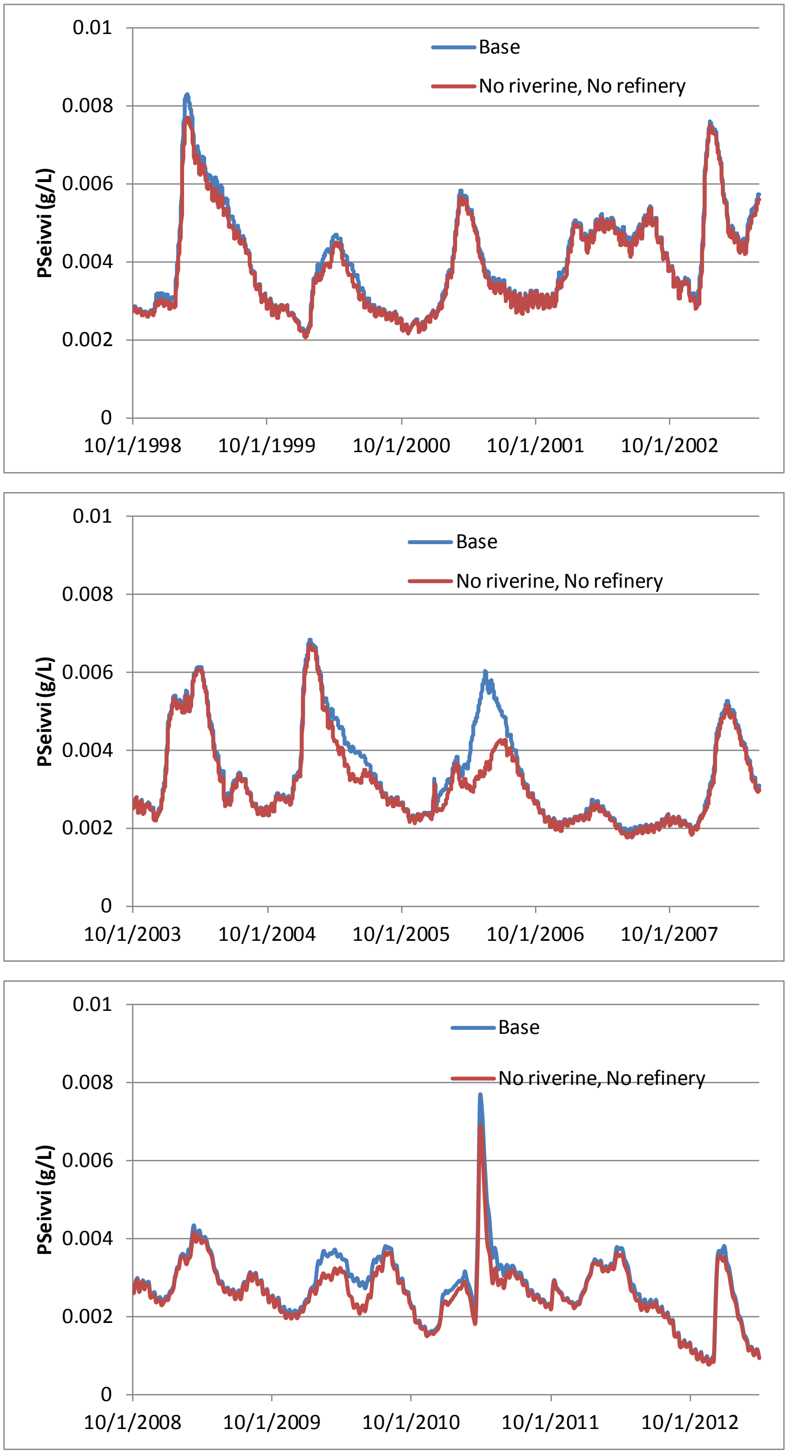


Figure 3-35
Simulated concentrations of particulate selenite and selenate under current conditions and no riverine and local inputs at Carquinez Strait.

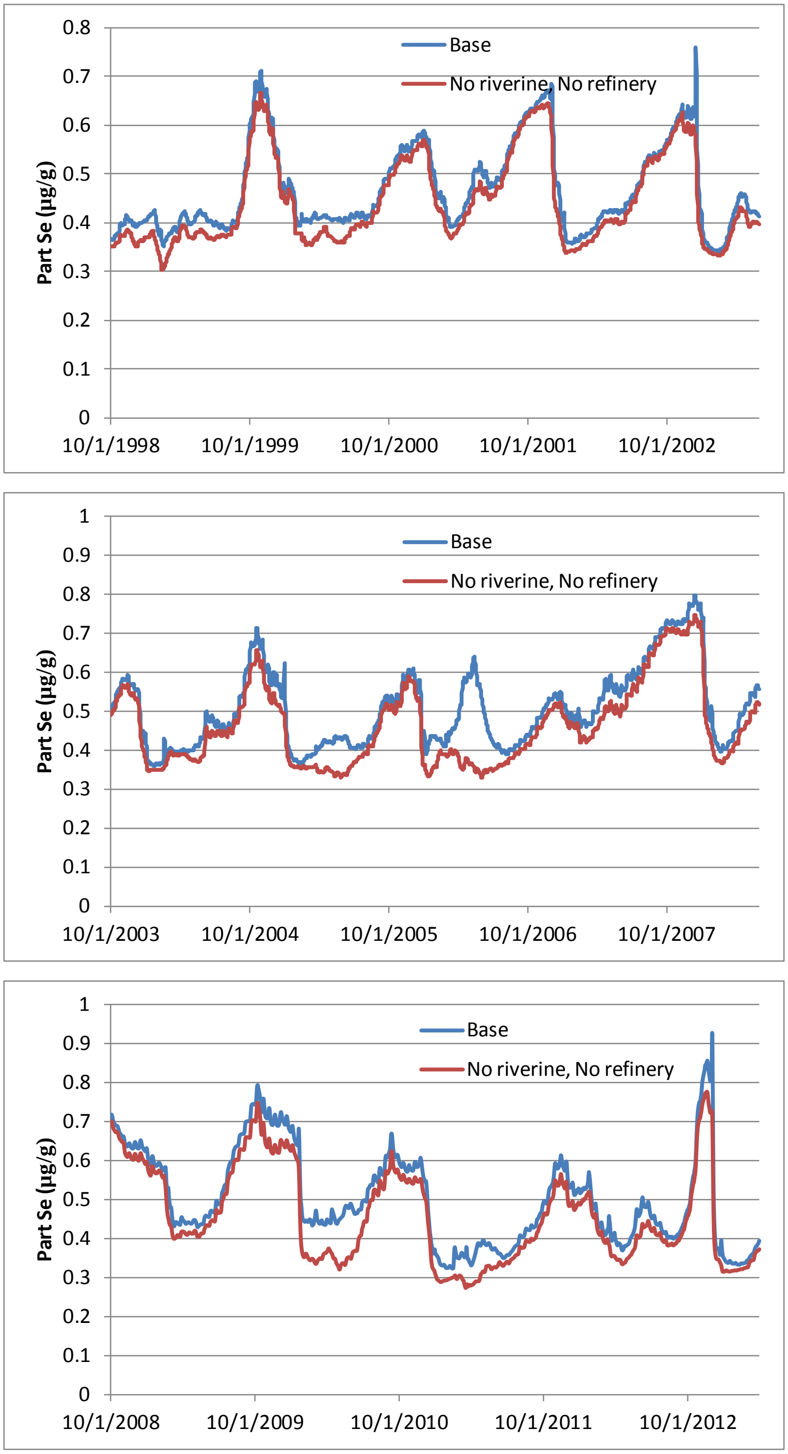


Figure 3-36
Simulated concentrations of particulate selenium under current conditions and no riverine and local inputs at Carquinez Strait.

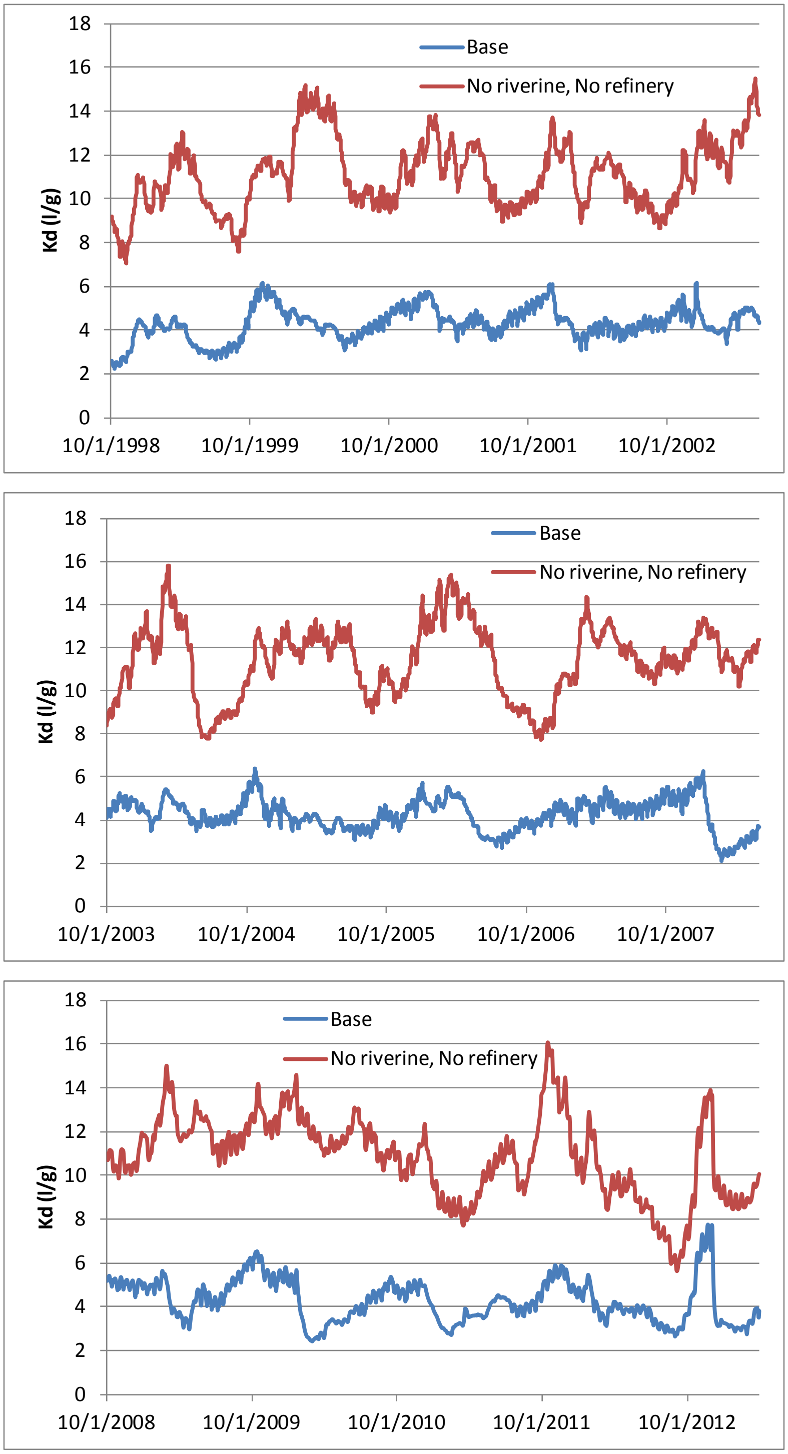


Figure 3-37
Simulated Kds under current conditions and no riverine and local inputs at Carquinez Strait.

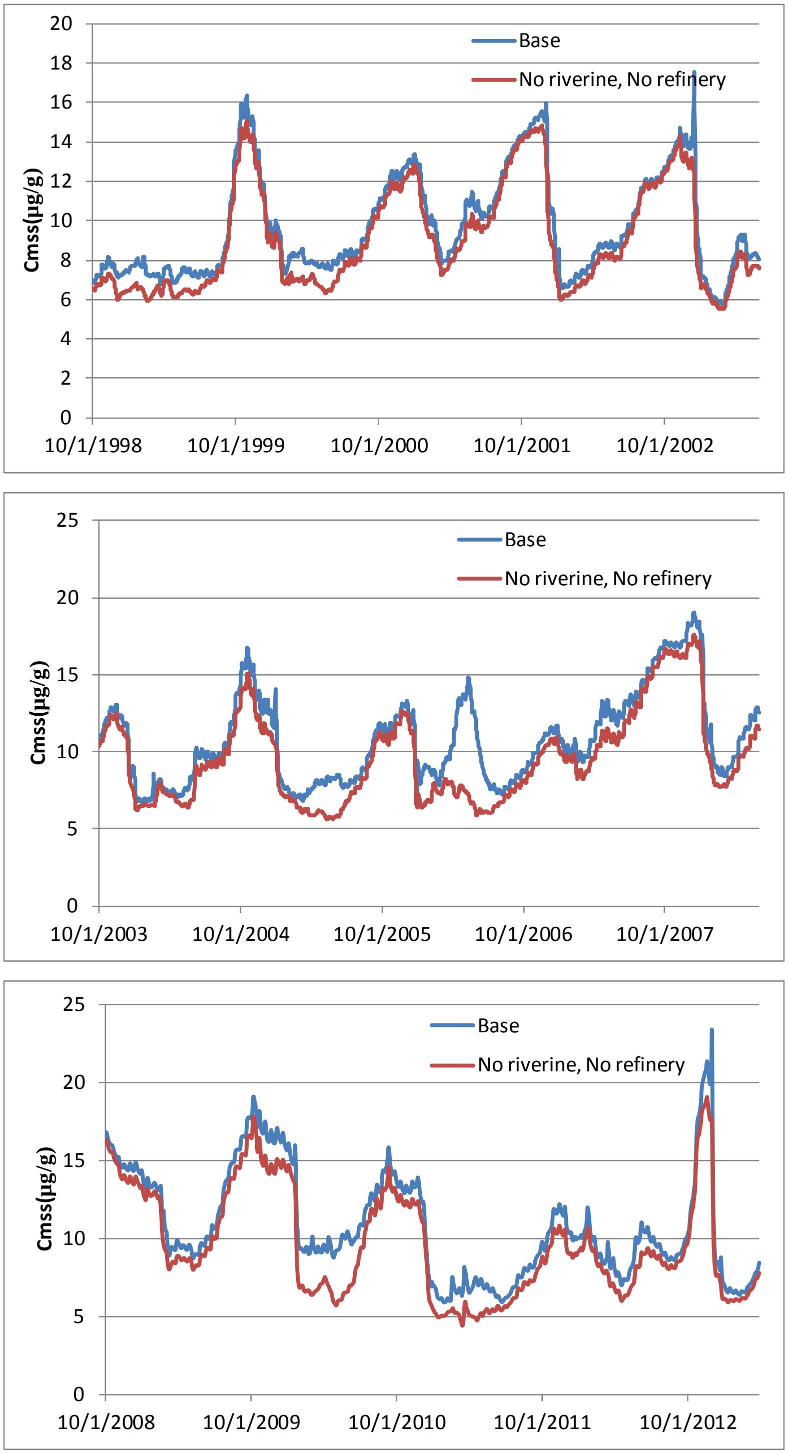


Figure 3-38
Simulated concentrations of selenium in clams under current conditions and no riverine and local inputs at Carquinez Strait.

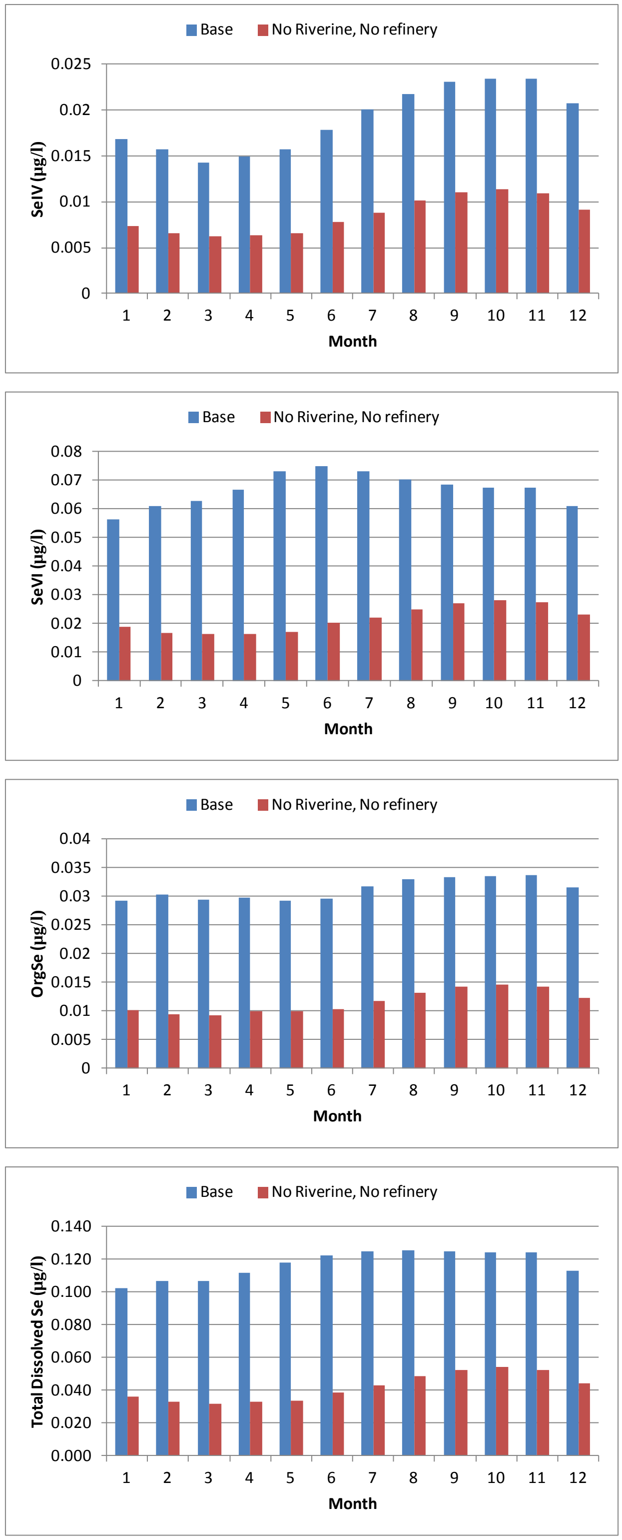


Figure 3-39
Simulated concentrations of dissolved selenium under current conditions and no riverine and local inputs at Carquinez Strait.

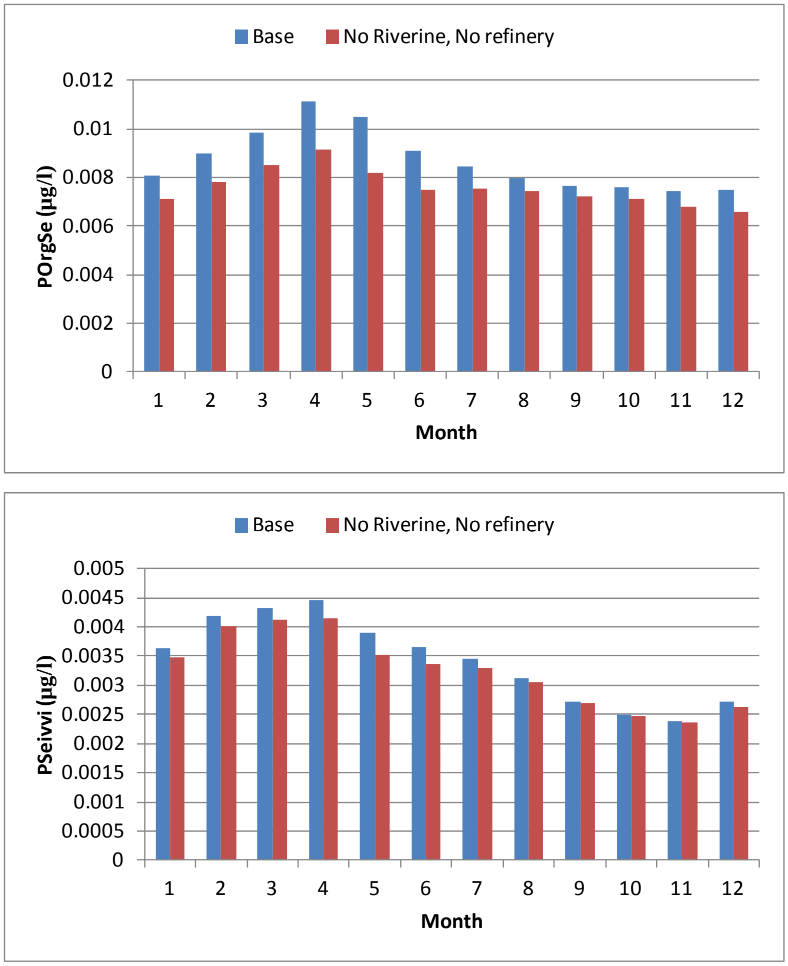


Figure 3-40
Simulated changes in particulate organic selenide and particulate selenite and selenate due to riverine and local load reductions to zero at Carquinez Strait.

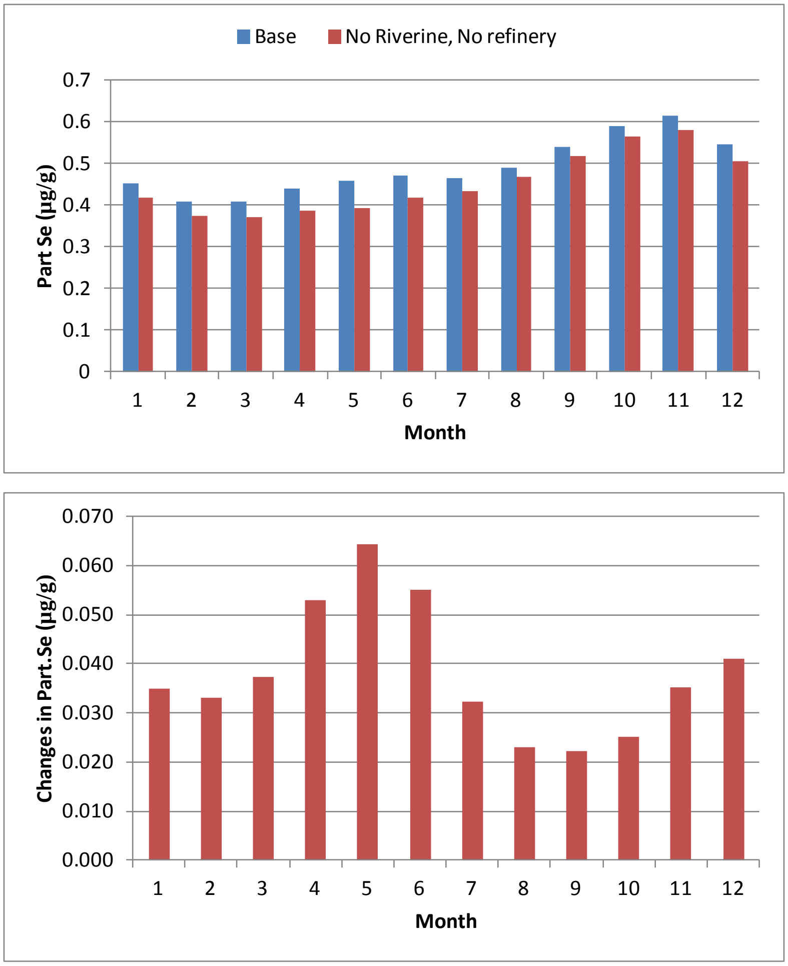


Figure 3-41
Simulated changes in particulate selenium due to riverine and local load reductions to zero at Carquinez Strait.

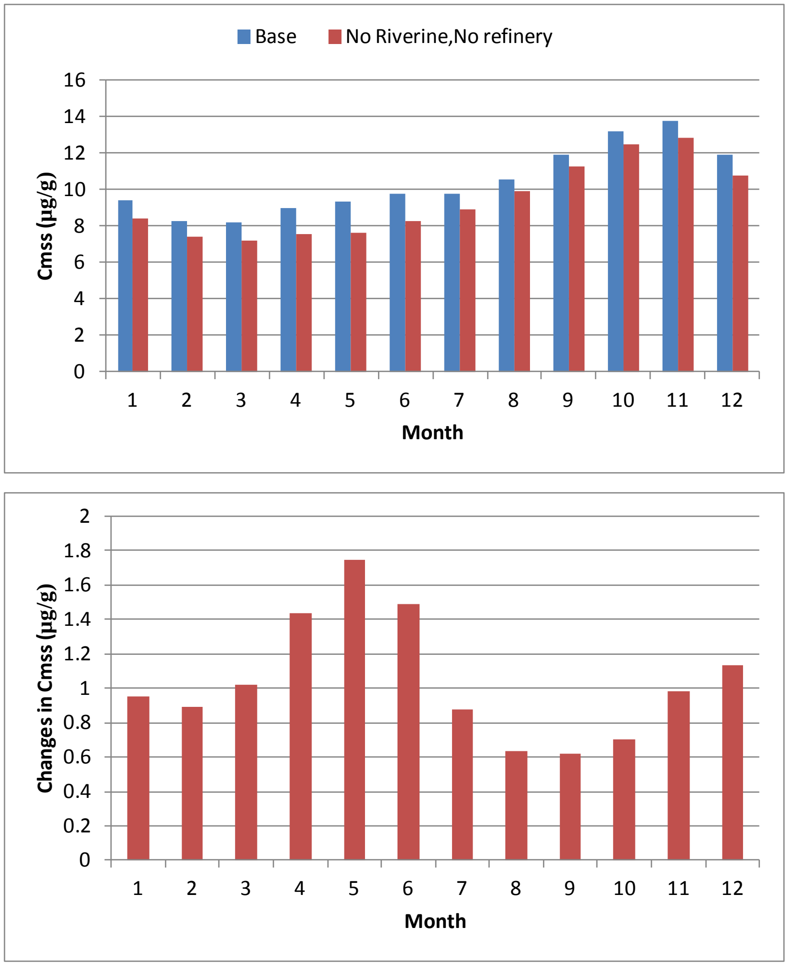


Figure 3-42
Simulated changes in clam selenium concentrations due to riverine and local load reductions at Carquinez Strait.

Table 3-10
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to riverine and local dissolved selenium loads reductions to zero for Oct. 30, 1999 transect.

Species	Base Case	No riverine, No refinery inputs	Change	% Change
Total Dissolved	0.091 (0.014 SeIV, 0.057 SeVI, 0.02 OrgSe)	0.027 (0.005 SeIV, 0.015 SeVI, 0.007 OrgSe)	-0.064 (0.009 SeIV, 0.043 SeVI, 0.013 OrgSe)	-70.3
Total Particulate (µg/g)	0.563 (0.33 POrgSe, 0.118 PSeivvi, 0.118 PSe0)	0.548 (0.31 POrgSe, 0.117 PSeivvi, 0.117 PSe0)	-0.016 (0.014 POrgSe, 0.001 PSeivvi, 0.001 PSe0)	-2.8

Table 3-11
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to riverine and local dissolved selenium loads reductions to zero for Oct. 30, 1999 transect.

Species	Base Case	No riverine, No refinery inputs	Change	% Change
Total Dissolved	0.121 (0.02 SeIV, 0.07 SeVI, 0.03 OrgSe)	0.059 (0.013 SeIV, 0.033 SeVI, 0.014 OrgSe)	-0.062 (0.007 SeIV, 0.037 SeVI, 0.016 OrgSe)	-51.2
Total Particulate (µg/g)	0.712 (0.49 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.667 (0.446 POrgSe, 0.125 PSeivvi, 0.096 PSe0)	-0.045 (0.044 POrgSe, 0.001 PSeivvi, 0 PSe0)	-6.3

Table 3-12
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to riverine and local dissolved selenium loads reductions to zero for Oct. 30, 1999 transect.

Species	Base Case	No riverine, No refinery inputs	Change	% Change
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.066 (0.015 SeIV, 0.037 SeVI, 0.015 OrgSe)	-0.035 (0.006 SeIV, 0.021 SeVI, 0.008 OrgSe)	-34.7
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	0.821 (0.607 POrgSe, 0.131 PSeivvi, 0.083 PSe0)	-0.051 (0.050 POrgSe, 0.001 PSeivvi, 0 PSe0)	-5.8

3.4 Constant Boundary Scenario

A scenario with constant selenium concentrations at all boundaries was simulated to evaluate the impacts of naturally varying flows in the system. The constant values of selenium concentrations used at the boundaries are averages of observed values at Sacramento River at Freeport and San Joaquin River at Vernalis from USGS. The constant values used are: 0.095 µg/L at Freeport, 0.57 µg/L at Vernalis, 0.10 µg/L at east side tributaries and 0.11 µg/L from agricultural returns. The results suggest slightly higher predicted dissolved and particulate selenium concentrations and similar Kds in the bay by using the average constant concentrations at boundaries (Figure 3-43 to Figure 3-54). The results also suggested somewhat lower variation in selenium concentrations in particulates and the clams than when varying boundary concentrations are used. This scenario shows that a large part of the seasonal variation in concentrations of selenium in water, particulates, and clams is in fact controlled by the flow variation and not the concentration variation.

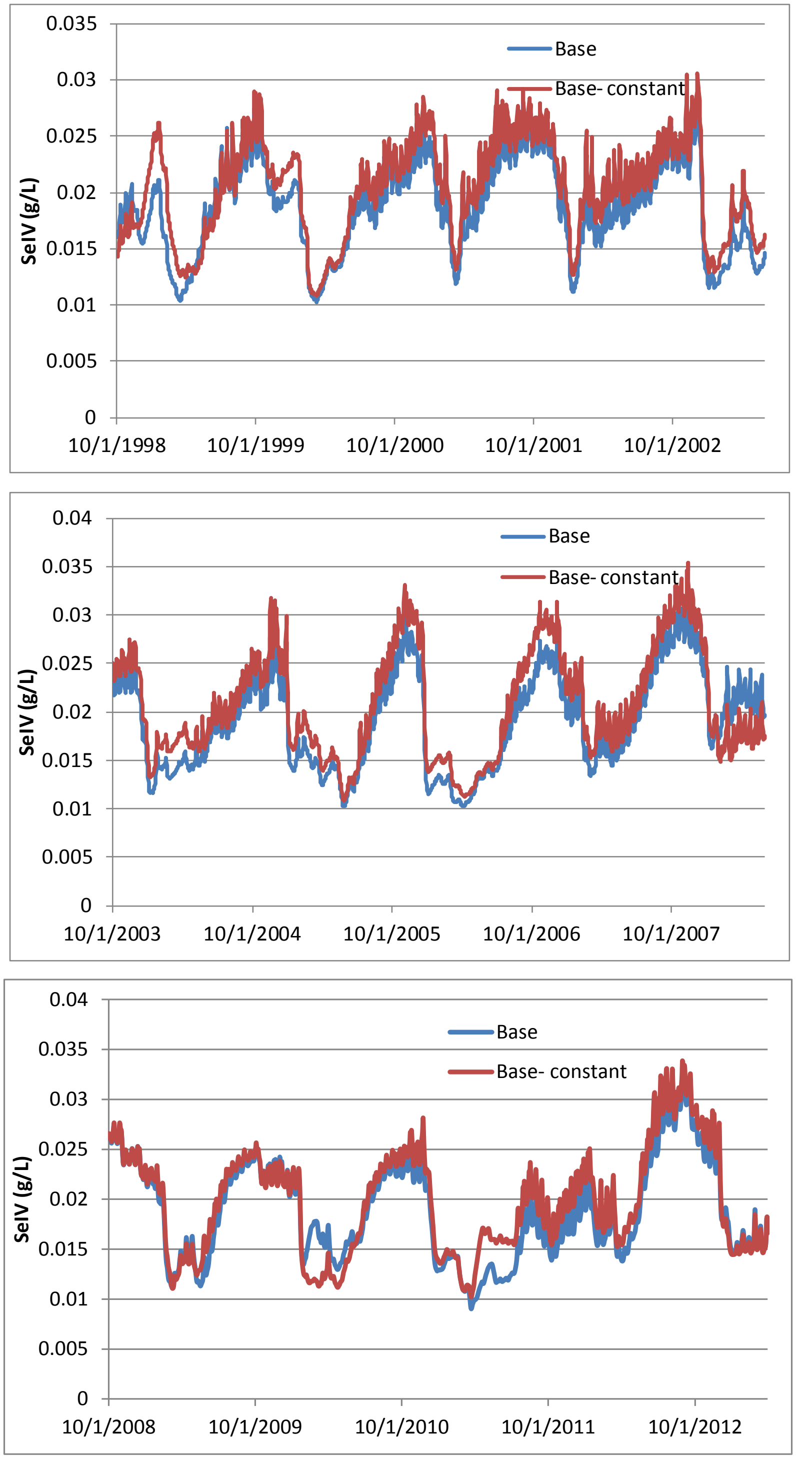


Figure 3-43
Simulated concentrations of selenite under constant boundary conditions at Carquinez Strait.

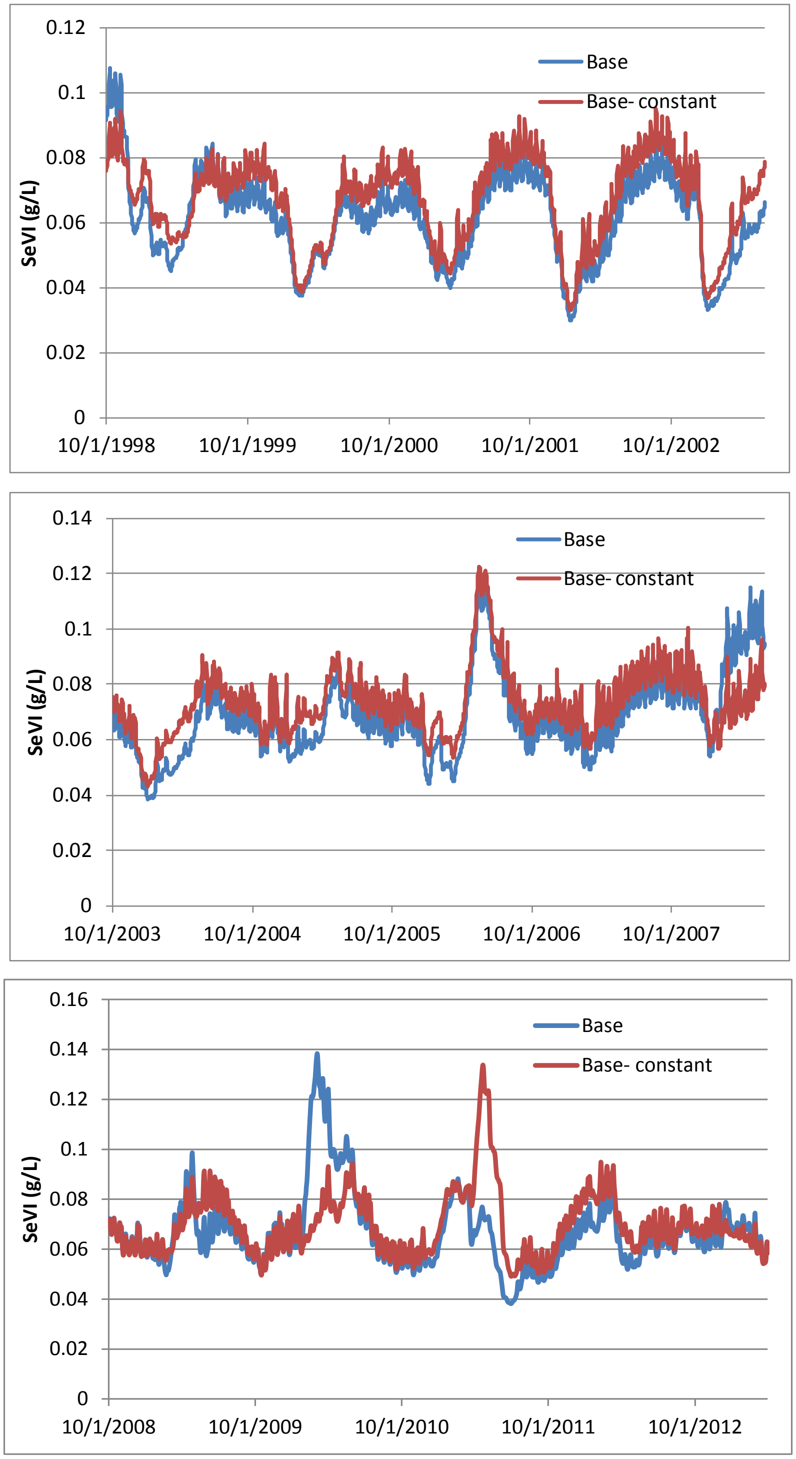


Figure 3-44
Simulated concentrations of selenate under constant boundary conditions at Carquinez Strait.

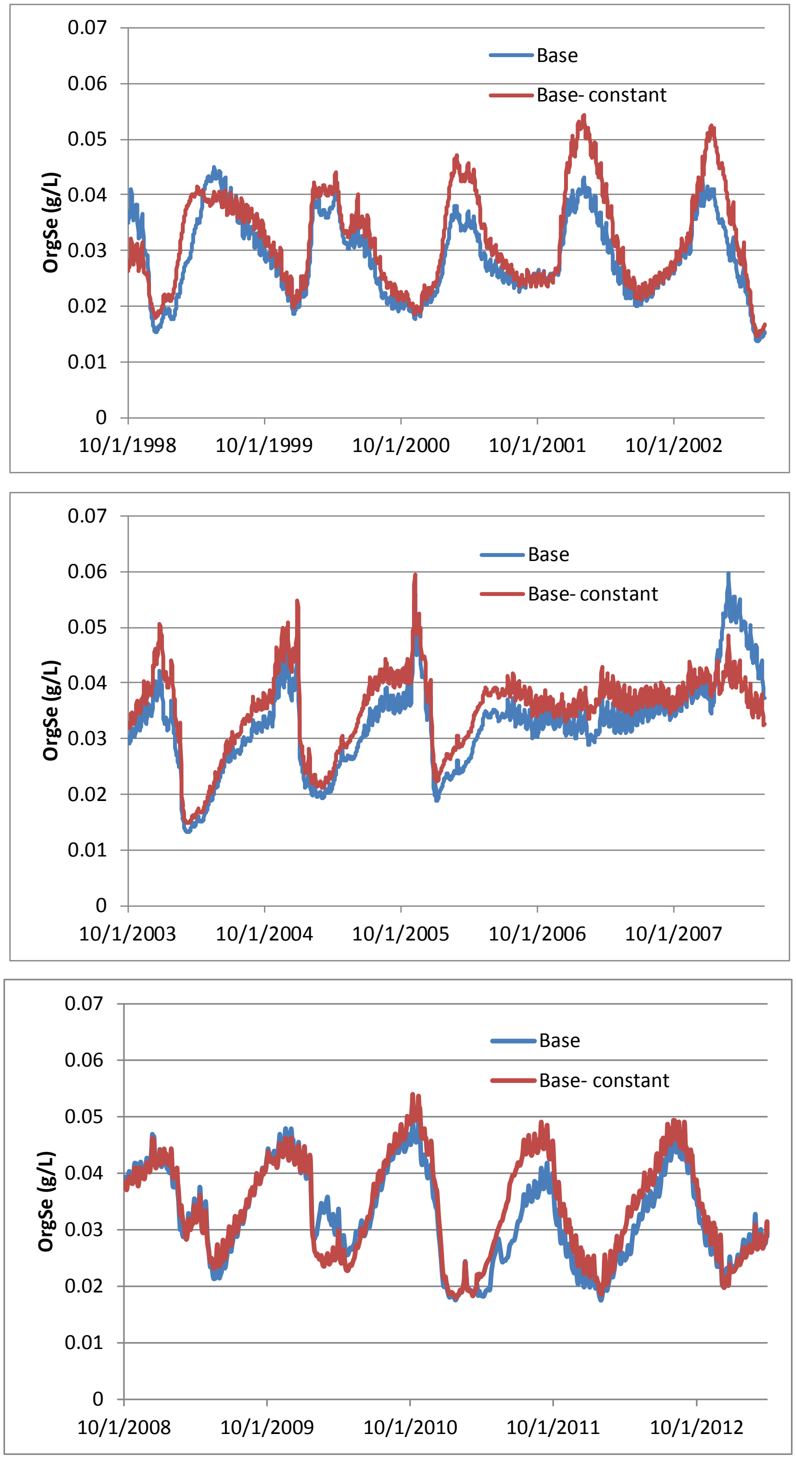


Figure 3-45
Simulated concentrations of organic selenide under constant boundary conditions at Carquinez Strait.

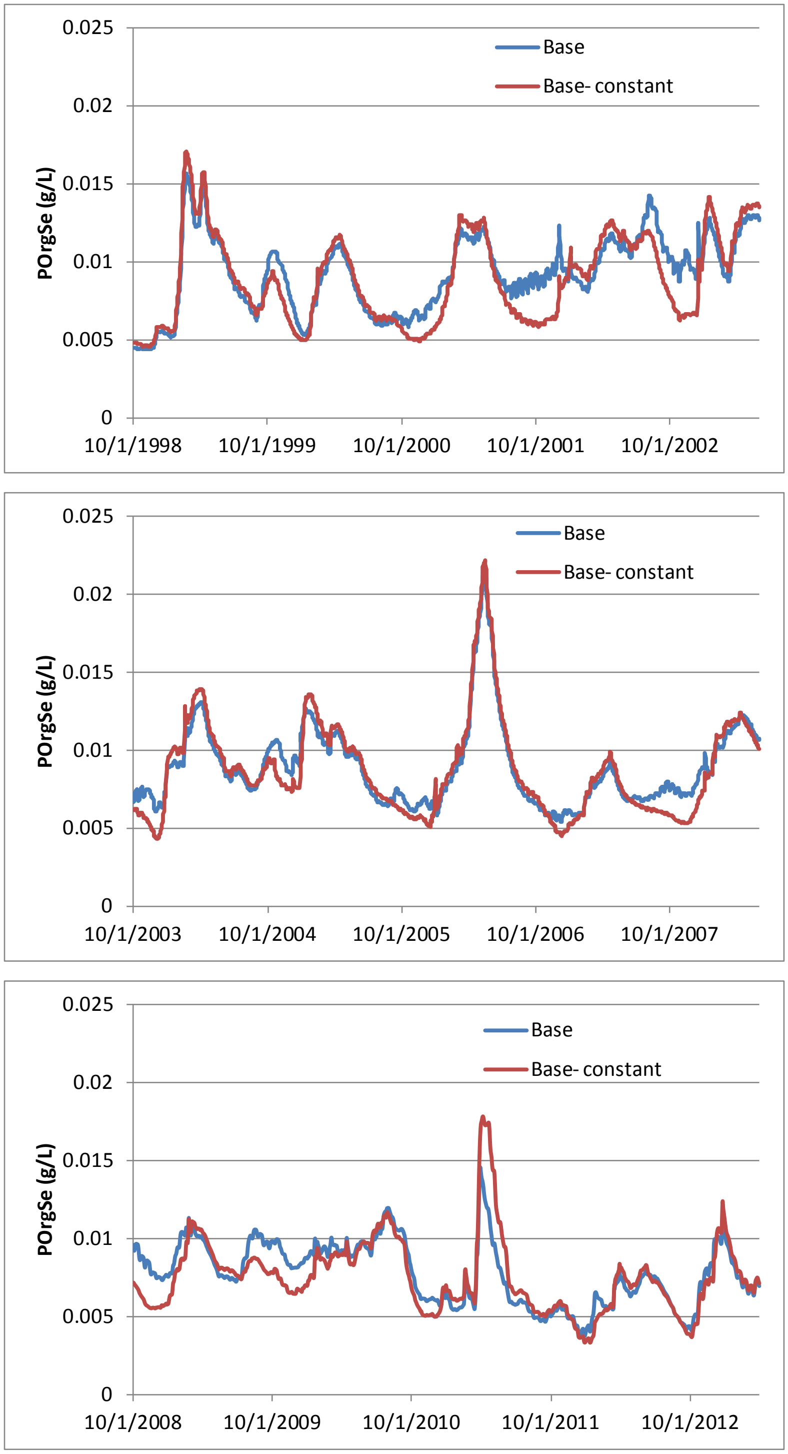


Figure 3-46
Simulated concentrations of particulate organic selenide under constant boundary conditions at Carquinez Strait.

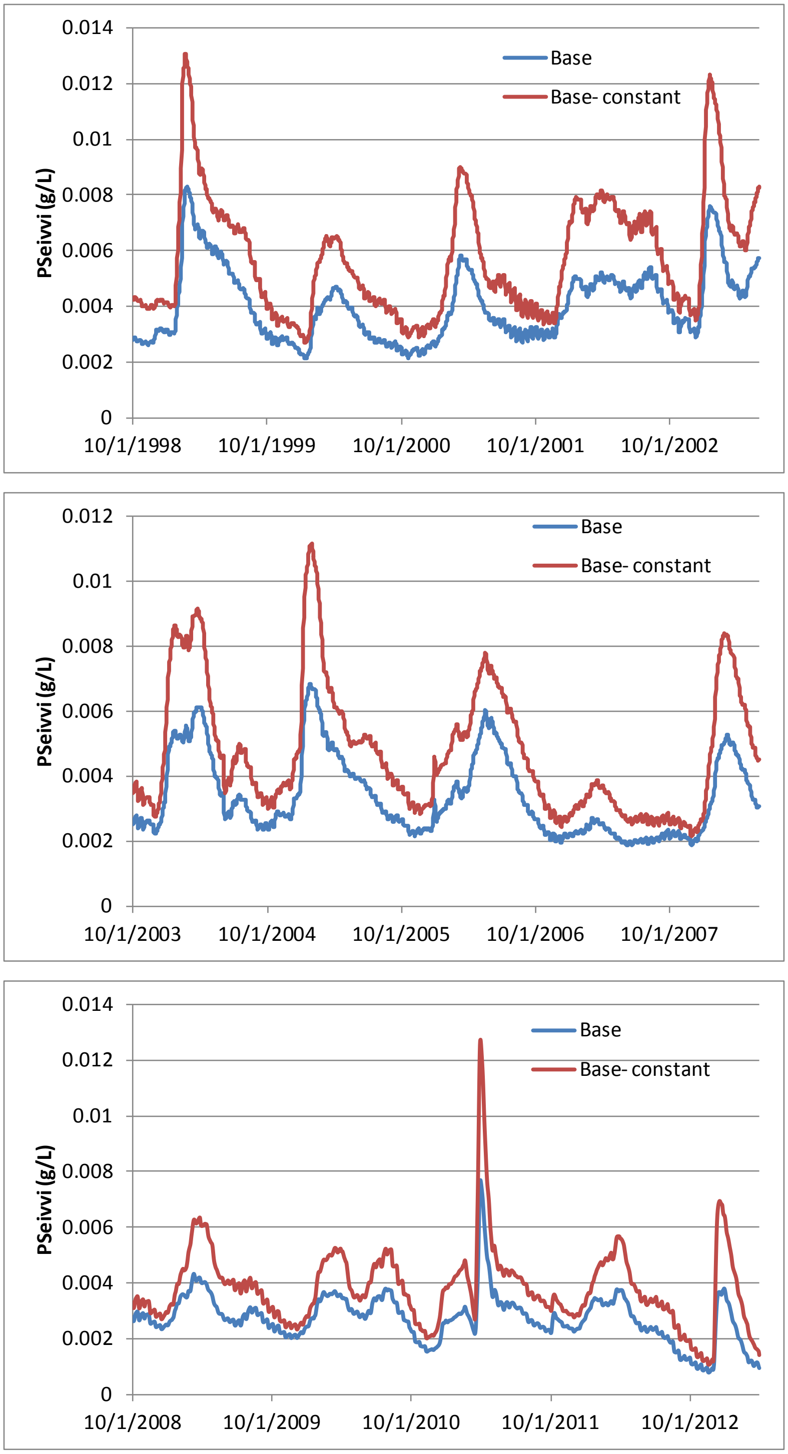


Figure 3-47
Simulated concentrations of particulate selenite and selenate under constant boundary conditions at Carquinez Strait.

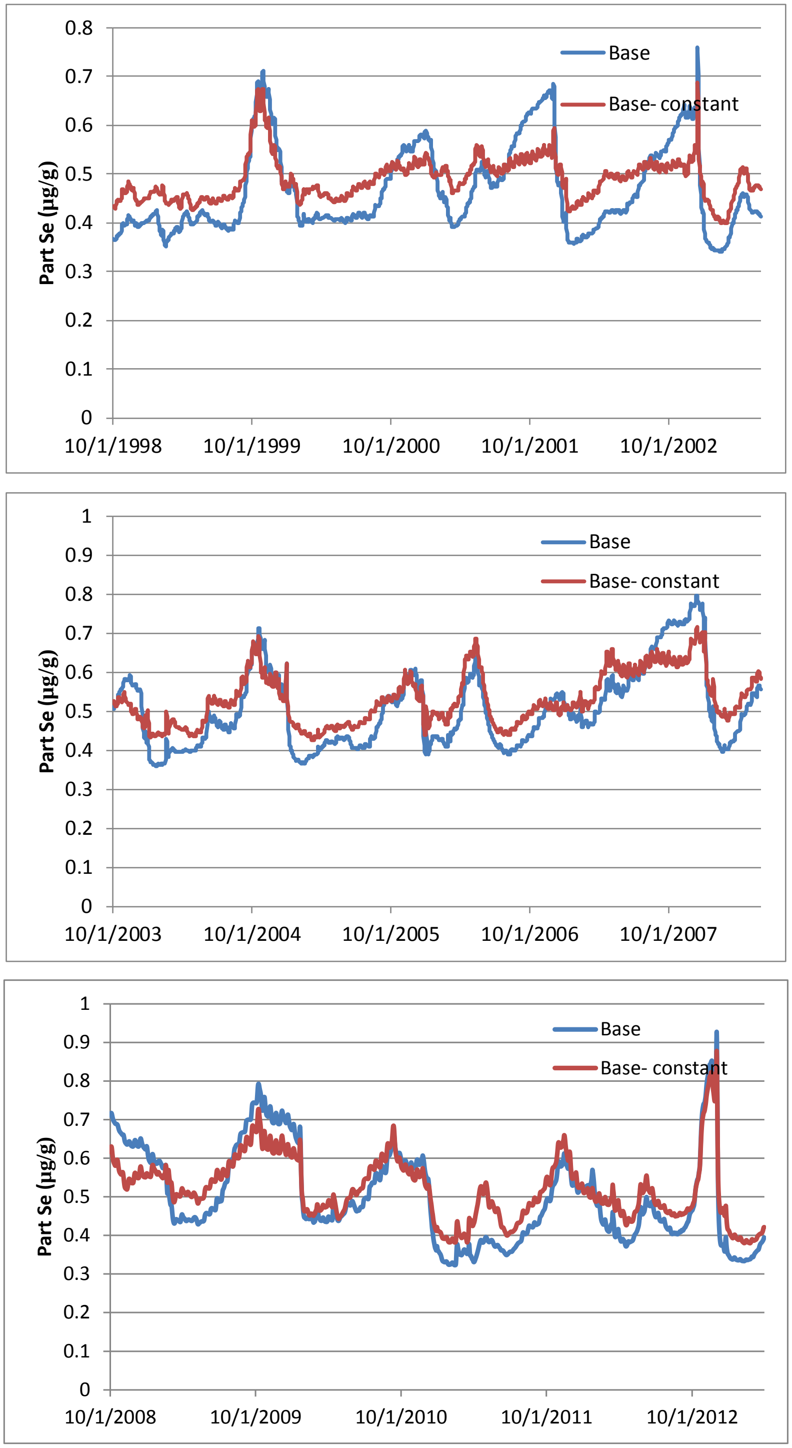


Figure 3-48
Simulated concentrations of particulate selenium under constant boundary conditions at Carquinez Strait.

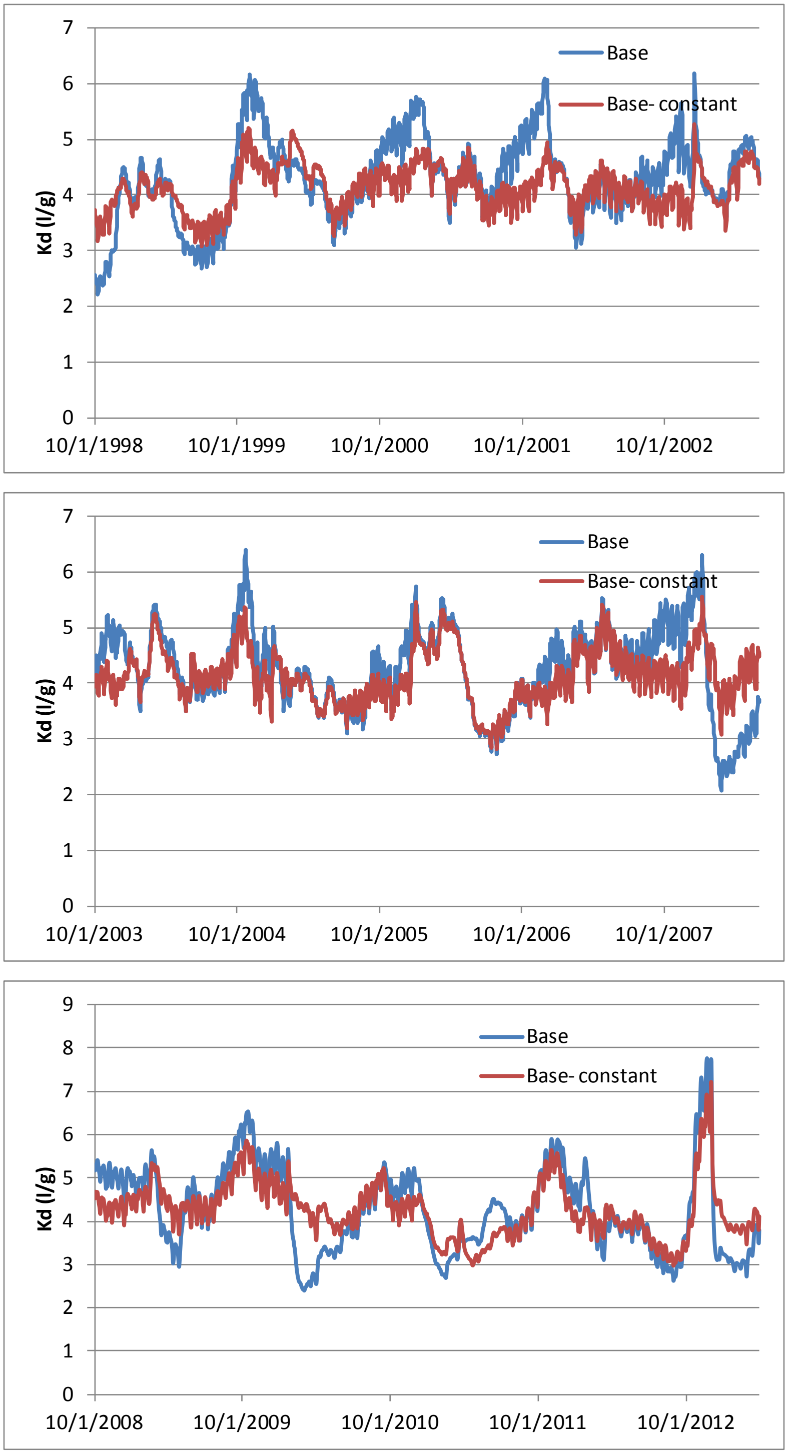


Figure 3-49
Simulated Kds under constant boundary conditions at Carquinez Strait.

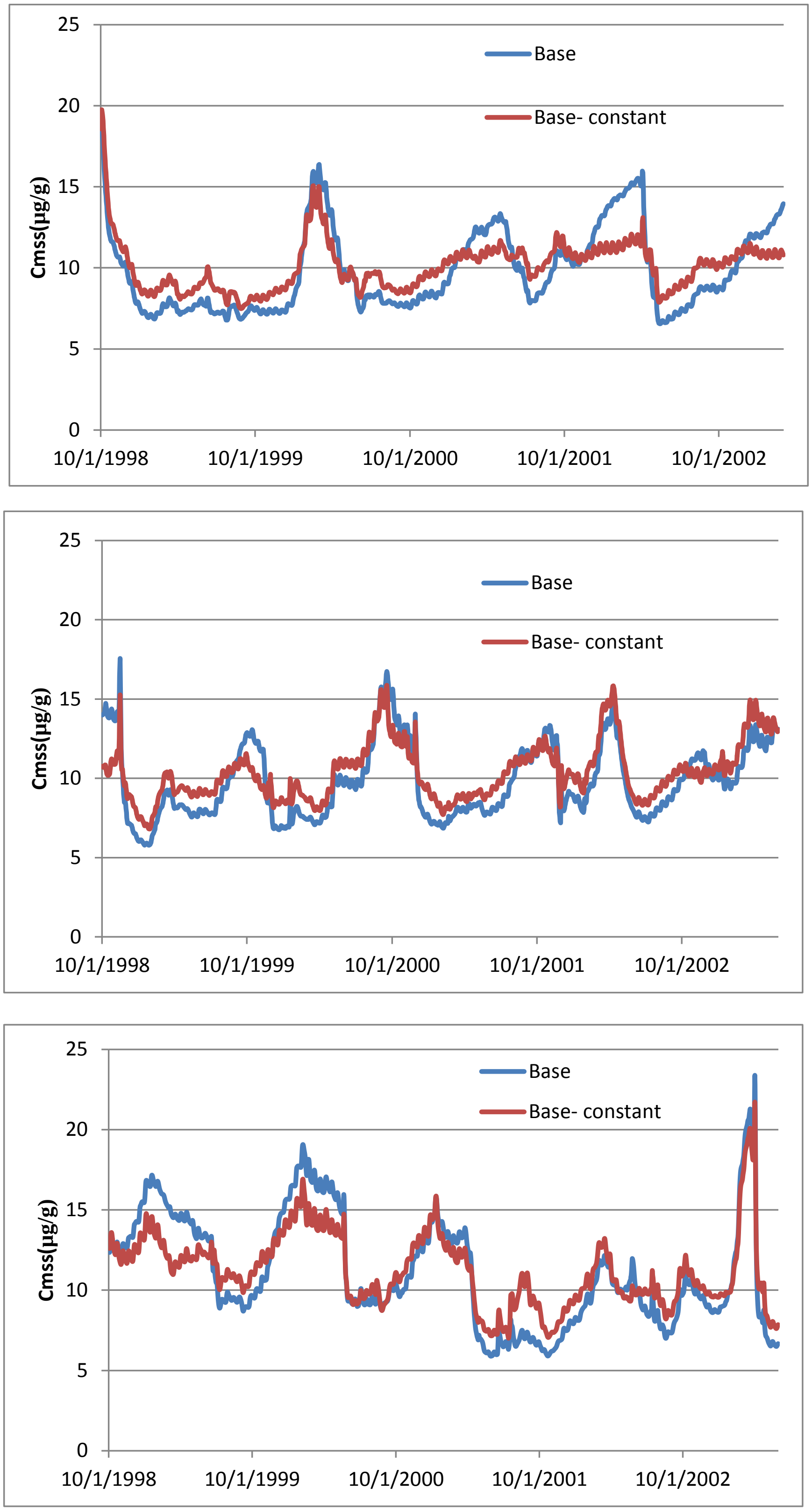


Figure 3-50
Simulated concentrations of selenium in clams under constant boundary conditions at Carquinez Strait.

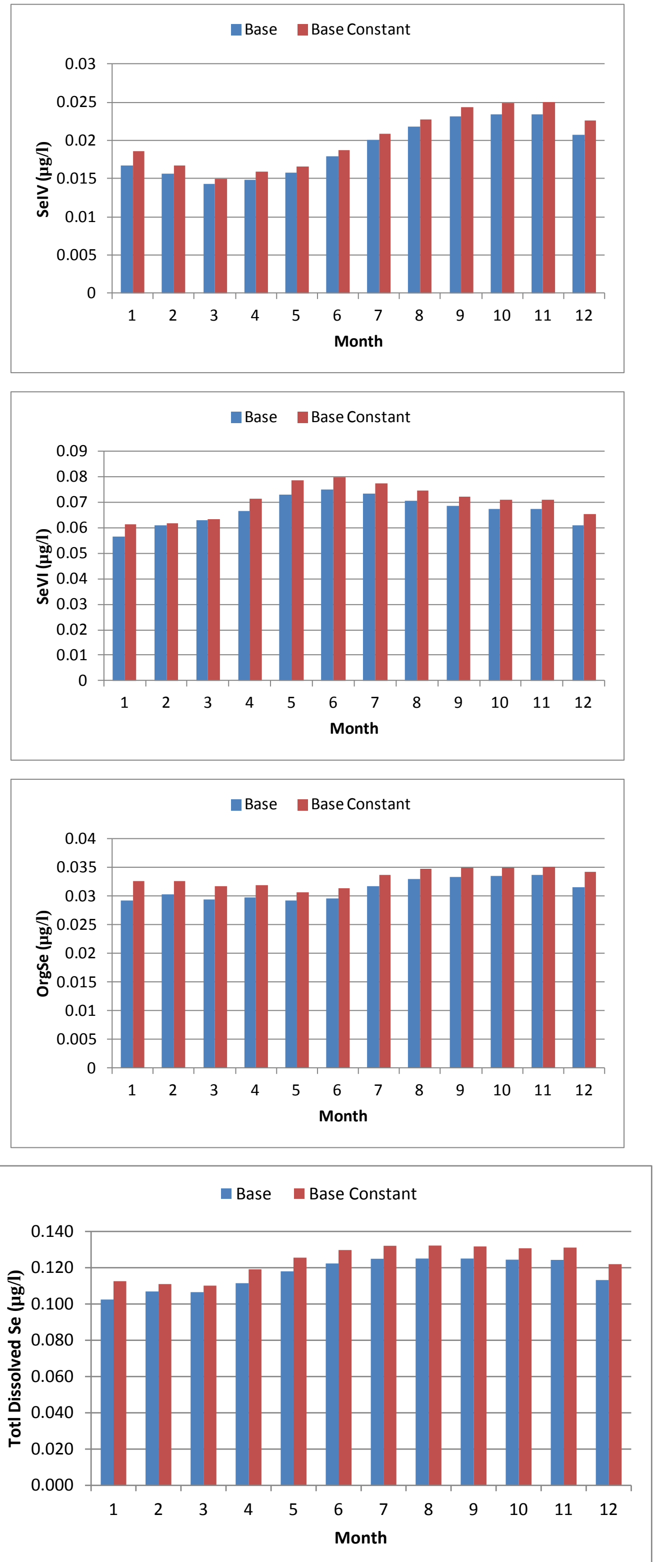


Figure 3-51
Simulated concentrations of dissolved selenium under constant boundary conditions at Carquinez Strait.

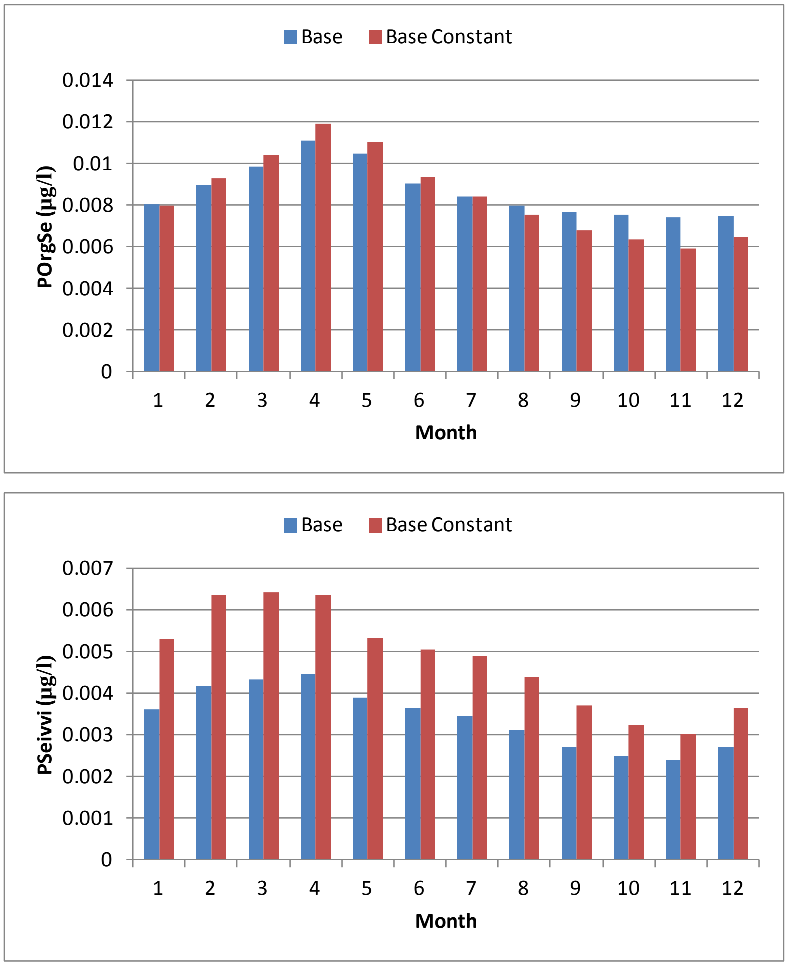


Figure 3-52
Simulated particulate organic selenide and particulate selenite and selenate under constant boundary conditions at Carquinez Strait.

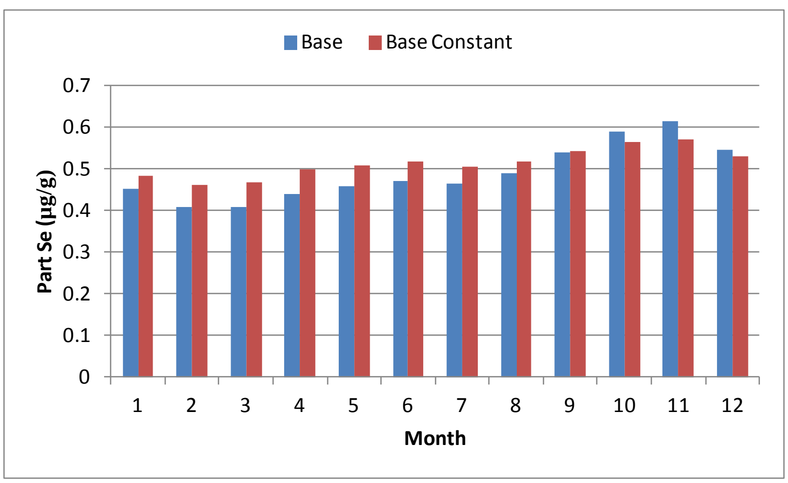


Figure 3-53
Simulated particulate selenium under constant boundary conditions at Carquinez Strait.

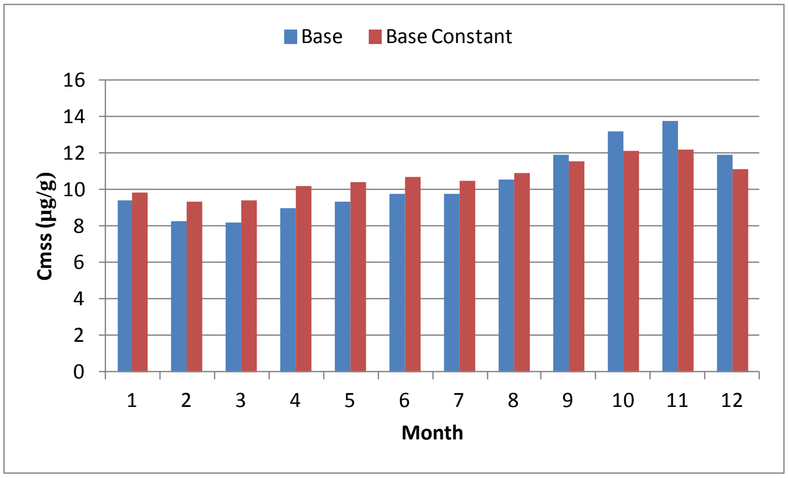


Figure 3-54
Simulated clam selenium concentrations under constant boundary conditions at Carquinez Strait.

3.5 Effects of Increasing Refinery Loads by a Factor of Two

The effects of changes to refinery loads on concentrations across the estuary were evaluated using ECoS by modifying all refinery loads, and leaving all other loads, hydrologic inputs for 1998-2012, and model constants at their previously calibrated values. The speciation of the refinery loads (i.e., percent attributed to selenate, selenite, and organic selenide) was not modified. In this section, we show the effects of a doubling of refinery loads. Results are presented as time series plots, and monthly bar charts. for the modeling period.

Important results are as follows.

- Figure 3-55 through Figure 3-57 show the change in individual selenium species at a representative mid-estuary location, Carquinez Strait. The effect of the doubling of refinery loads is most apparent in the dry months and is small to negligible during the wet periods. This is because of the effect of other larger loads in the system during the wet months, and because of the shorter residence times in the bay.
- Figure 3-58 shows that Kd values decrease under the higher load conditions, as a consequence of particulate concentrations not increasing in proportion to the refinery load increase that consists predominantly of dissolved selenium.
- Figure 3-59 shows the monthly average load across the 1998-2012 simulation period for dissolved selenium species (selenate, selenite, organic selenium), and for total dissolved selenium. Concentrations are higher in the dry periods, typically, July through November, during which the effect of the refinery load increase is also more pronounced.
- Figure 3-60 shows that the particulate selenium increases are much smaller than the corresponding dissolved selenium increases. Although small, the effects are somewhat larger during dry and fall months, especially September through November. The clam concentrations match these increases (Figure 3-61).
- Data representing the dry season of 1999 are shown in tabular form for three locations in North San Francisco Bay, going east to west: Suisun Bay, Carquinez Strait, and San Pablo Bay (Table 13 through Table 15). At all three locations, the increases is particulate concentrations are much smaller than the dissolved phase increases (1.4-4.5% increase in particulate selenium compared to 14-30% increase in dissolved selenium). The difference is smaller as one moves west, but even at

San Pablo Bay, the percent change in particulate selenium is one-fifth the change in dissolved selenium.

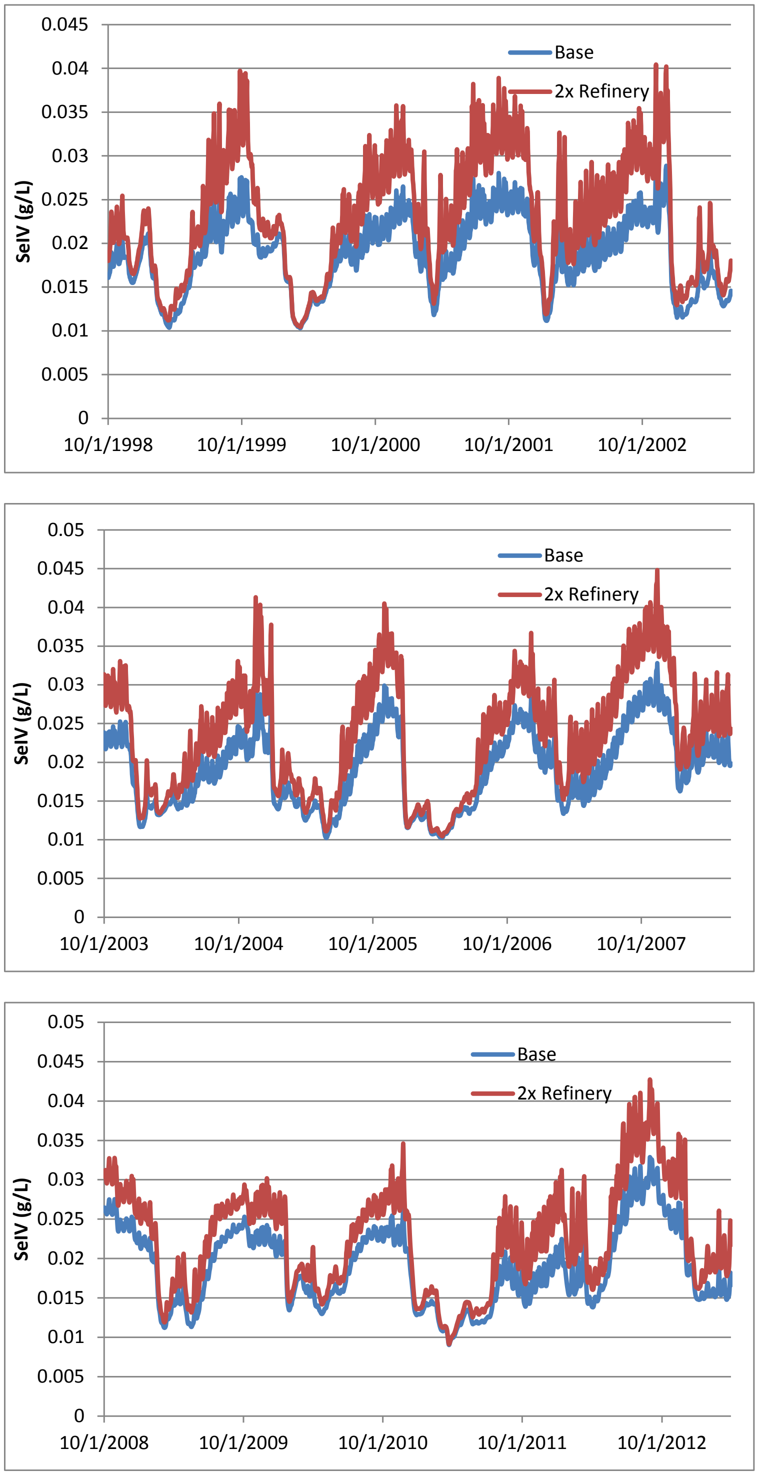


Figure 3-55
Simulated concentrations of selenite under current conditions and doubling of refinery load scenario at Carquinez Strait (blue = current baseline conditions; red = increased refinery load).

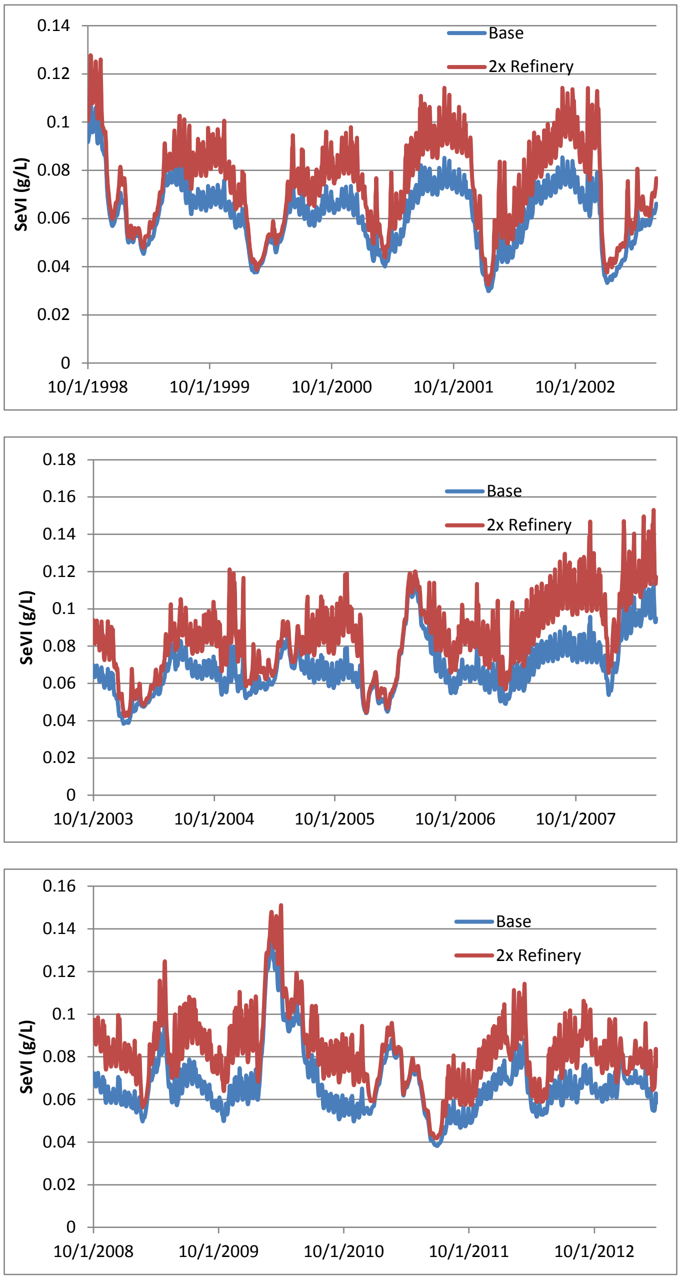


Figure 3-56
Simulated concentrations of selenate under current conditions and doubling of refinery load scenario at Carquinez Strait.

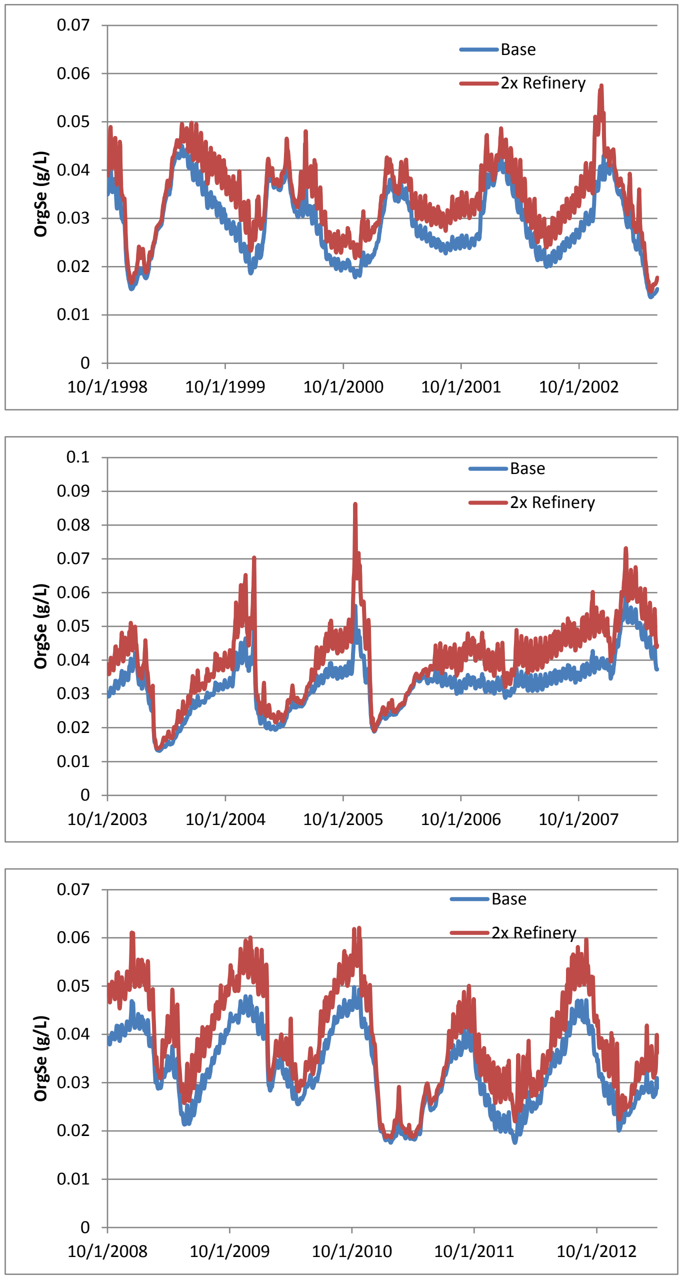


Figure 3-57
Simulated concentrations of organic selenide under current conditions and doubling of refinery load scenario at Carquinez Strait.

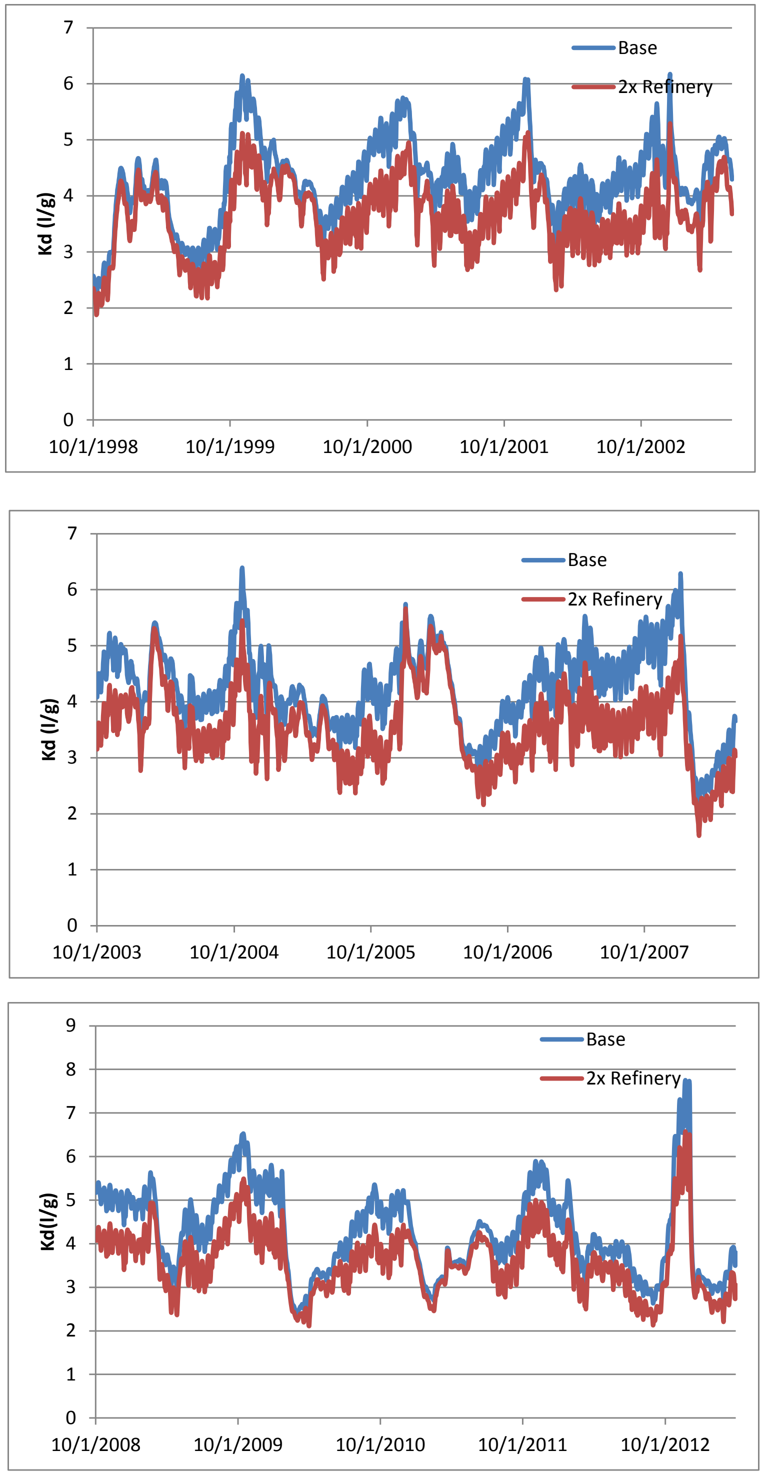


Figure 3-58
Simulated Kd under current conditions and doubling of refinery load scenario at Carquinez Strait.

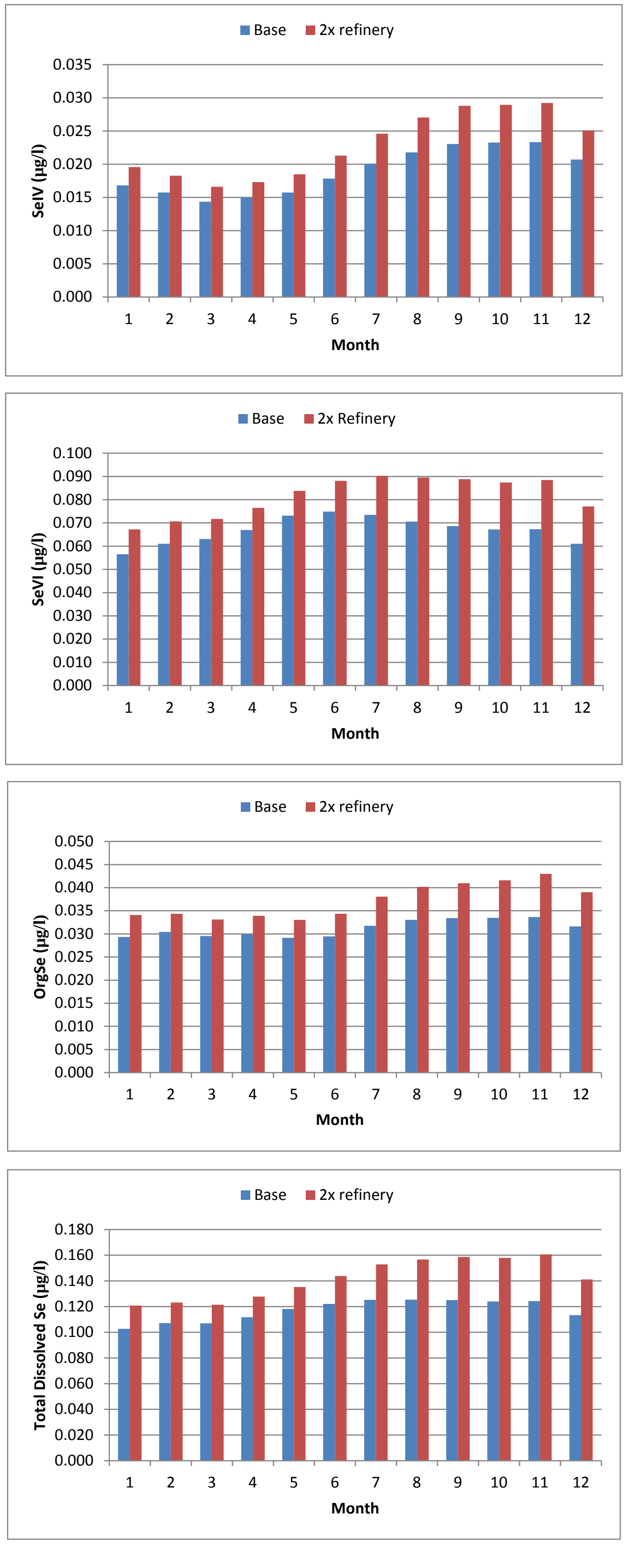


Figure 3-59
Simulated concentrations of dissolved selenium under current conditions and doubling of refinery load scenario at Carquinez Strait.

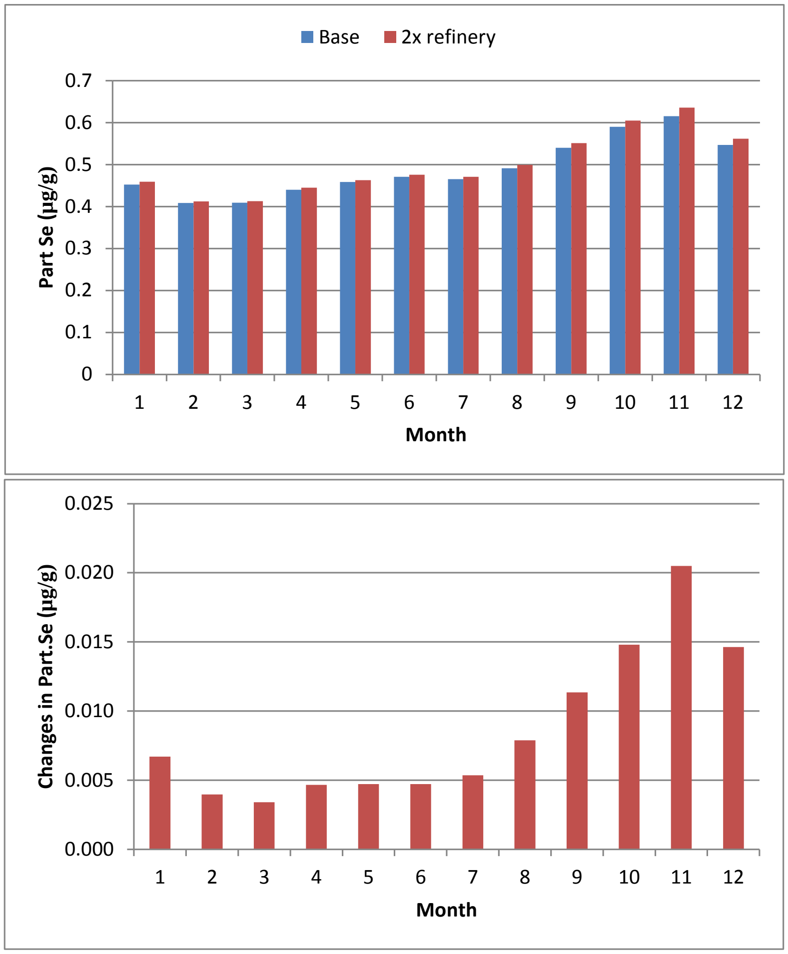


Figure 3-60
Simulated changes in particulate selenium due to doubling of refinery loads at Carquinez Strait.

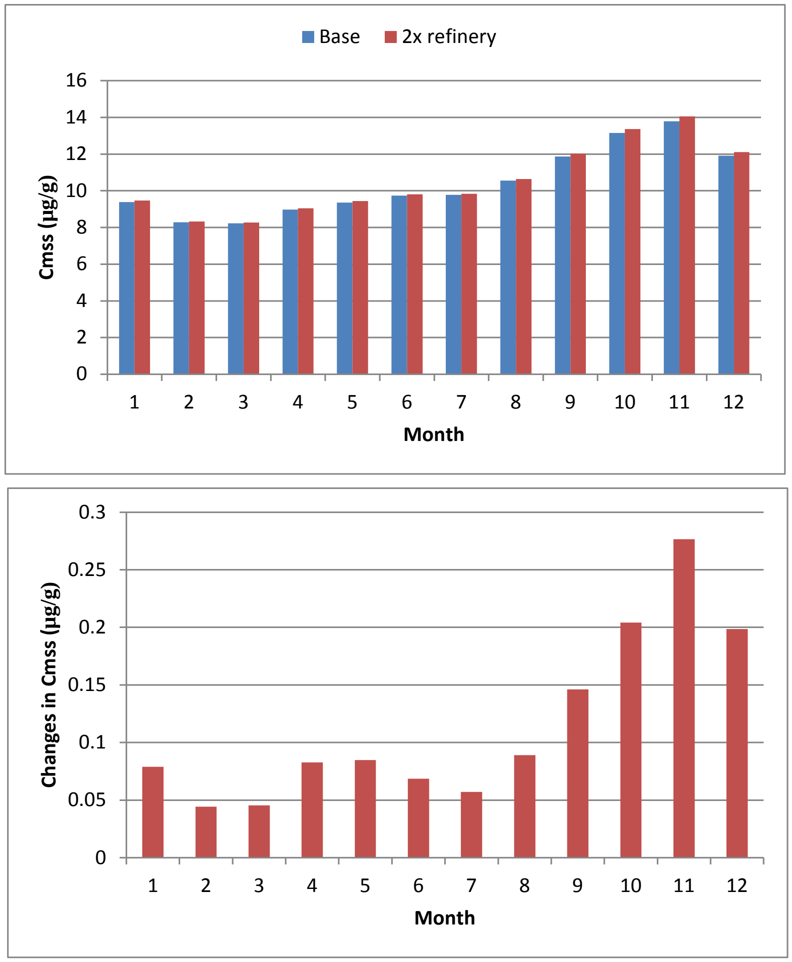


Figure 3-61
Simulated changes in clam selenium concentrations due to doubling of refinery loads at Carquinez Strait.

Table 13
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to double refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Double refinery	Change	Change (%)
Total Dissolved	0.091 (0.014 SeIV, 0.057 SeVI, 0.02 OrgSe)	0.104 (0.017 SeIV, 0.064 SeVI, 0.024 OrgSe)	0.013 (0.003 SeIV, 0.007 SeVI, 0.004 OrgSe)	14%
Total Particulate (µg/g)	0.563 (0.328 POrgSe, 0.118 PSeivvi, 0118 PSe0)	0.571 (0.333 POrgSe, 0.119 PSeivvi, 0.120 PSe0)	0.008 (0.005 POrgSe, 0.001 PSeivvi, 0.002 PSe0)	1.4%

Table 14
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to double refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Double refinery	Change	Change (%)
Total Dissolved	0.121 (0.02 SeIV, 0.07 SeVI, 0.03 OrgSe)	0.157 (0.029 SeIV, 0.09 SeVI, 0.037 OrgSe)	0.036 (0.006 SeIV, 0.02 SeVI, 0.009 OrgSe)	30%
Total Particulate (µg/g)	0.712 (0.490 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.744 (0.511 POrgSe, 0.129 PSeivvi, 0.104 PSe0)	0.032 (0.021 POrgSe, 0.003 PSeivvi, 0.008 PSe0)	4.5%

Table 15
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to double refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Double refinery	Change	Change (%)
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.122 (0.025 SeIV, 0.070 SeVI, 0.027 OrgSe)	0.021 (0.004 SeIV, 0.012 SeVI, 0.005 OrgSe)	21%
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	0.907 (0.684 POrgSe, 0.134 PSeivvi, 0.089 PSe0)	0.035 (0.026 POrgSe, 0.002 PSeivvi, 0.006 PSe0)	4%

3.6 Effects of Increasing Refinery Loads by a Factor of Five

The effects of changes to refinery loads on concentrations across the estuary were evaluated using ECoS by modifying all refinery loads, and leaving all other loads, hydrologic inputs for 1998-2012, and model constants at their previously calibrated values. The speciation of the refinery loads (i.e., percent attributed to selenate, selenite, and organic selenide) was not modified. In this section, we show the effects of increasing refinery loads by a factor of five. Results are presented as time series plots, and bar charts aggregating by month for the modeling period.

Important results are as follows.

- Figure 3-62 through Figure 3-64 show the change in individual selenium species at a representative mid-estuary location, Carquinez Strait. The effect of the increase of refinery loads is most apparent in the dry months and is small in the wet periods. The concentration increases are much larger than the case for doubling of refinery loads (shown separately).
- Figure 3-65 shows that Kd values decrease under the higher load conditions, as a consequence of particulate concentrations not increasing in proportion to the refinery load increase.
- Figure 3-66 shows the monthly average load across the 1998-2012 simulation period, by dissolved selenium species, and for all dissolved selenium. Concentrations are higher in the dry periods, typically, July through November, and the effect of the refinery load increase is also larger. During the months with the highest concentrations, total dissolved concentrations are slightly in excess of 0.25 μg/l.
- Figure 3-67 shows that the particulate selenium increases are much smaller than the corresponding dissolved selenium increases. Although small, the effects are somewhat larger in dry and fall months, especially September through November. The clam concentrations match these increases (Figure 3-68).
- Data are shown in tabular form in for three locations during the dry season in North San Francisco Bay, going east to west: Suisun Bay, Carquinez Strait, and San Pablo Bay (Table 3-16 through Table 3-18). At all three locations, the increases is particulate concentrations are much smaller than the dissolved phase increases (6-16% increase in particulate selenium compared to 59-119% increase in dissolved selenium). The difference is smaller as one moves west, but even at San Pablo Bay, the percent change in particulate selenium is one-fifth the change in dissolved selenium.

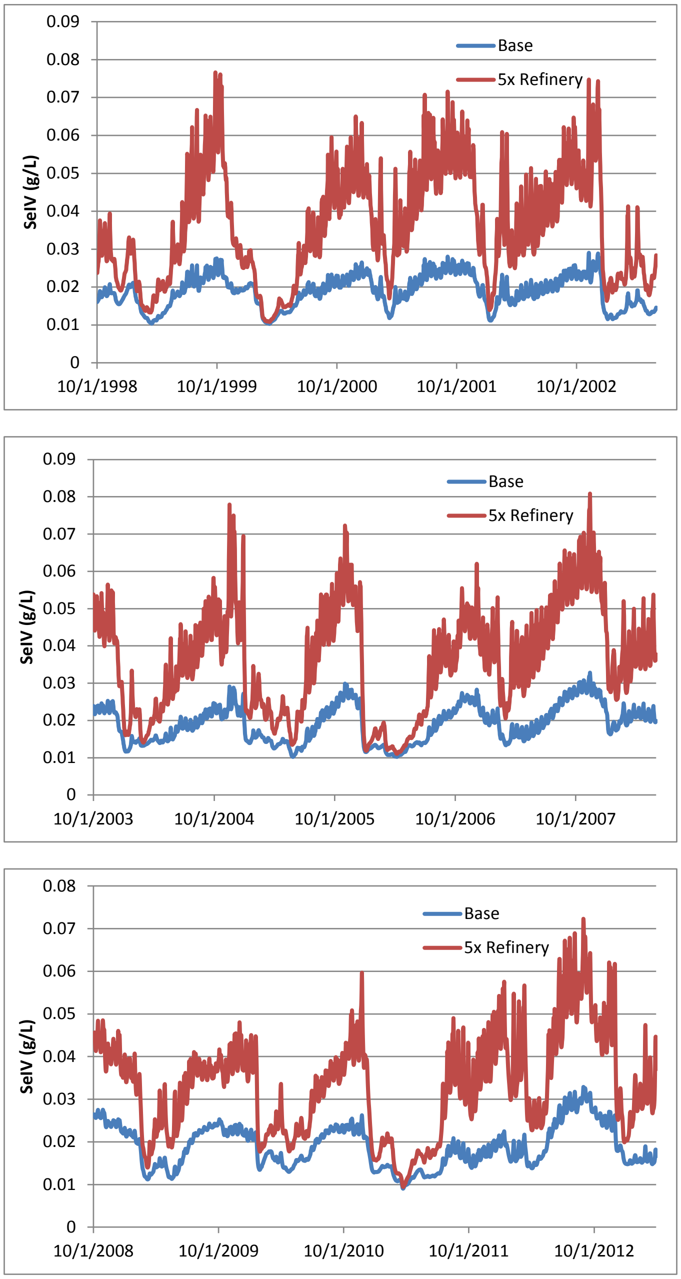


Figure 3-62
Simulated concentrations of selenite under current conditions and five times refinery load scenario at Carquinez Strait. (Blue= current loads; red = increased refinery loading).

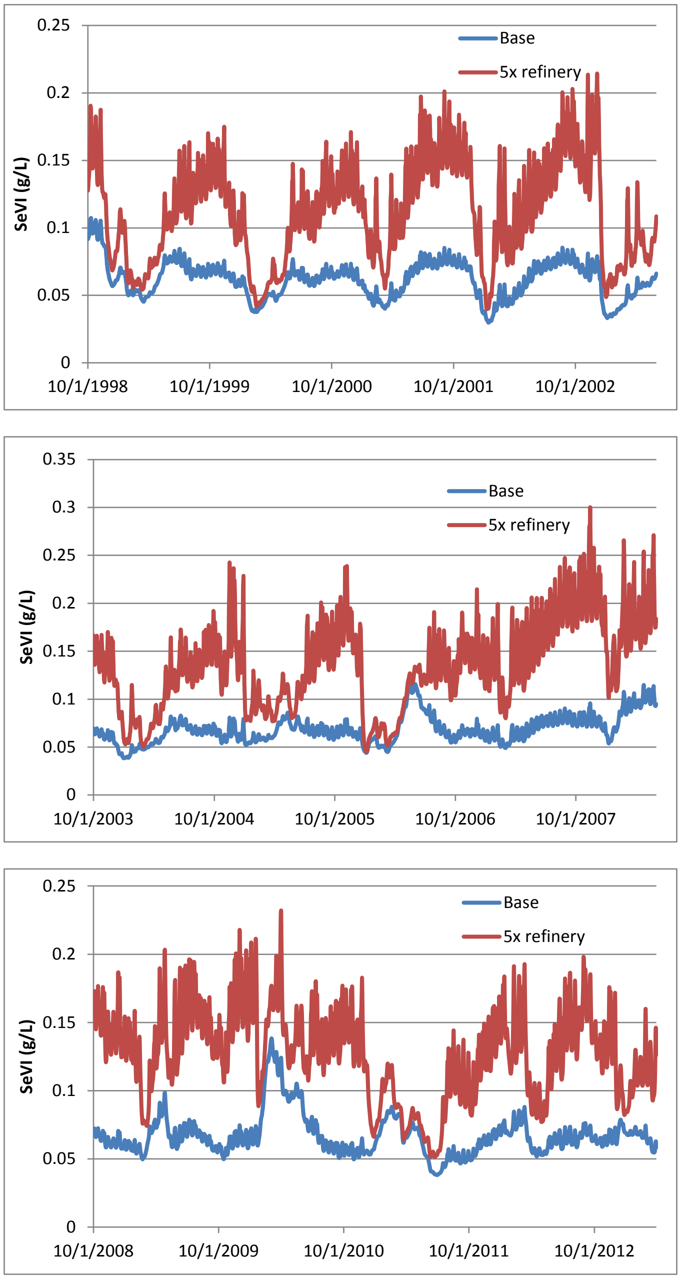


Figure 3-63
Simulated concentrations of selenate under current conditions and five times refinery load scenario at Carquinez Strait.

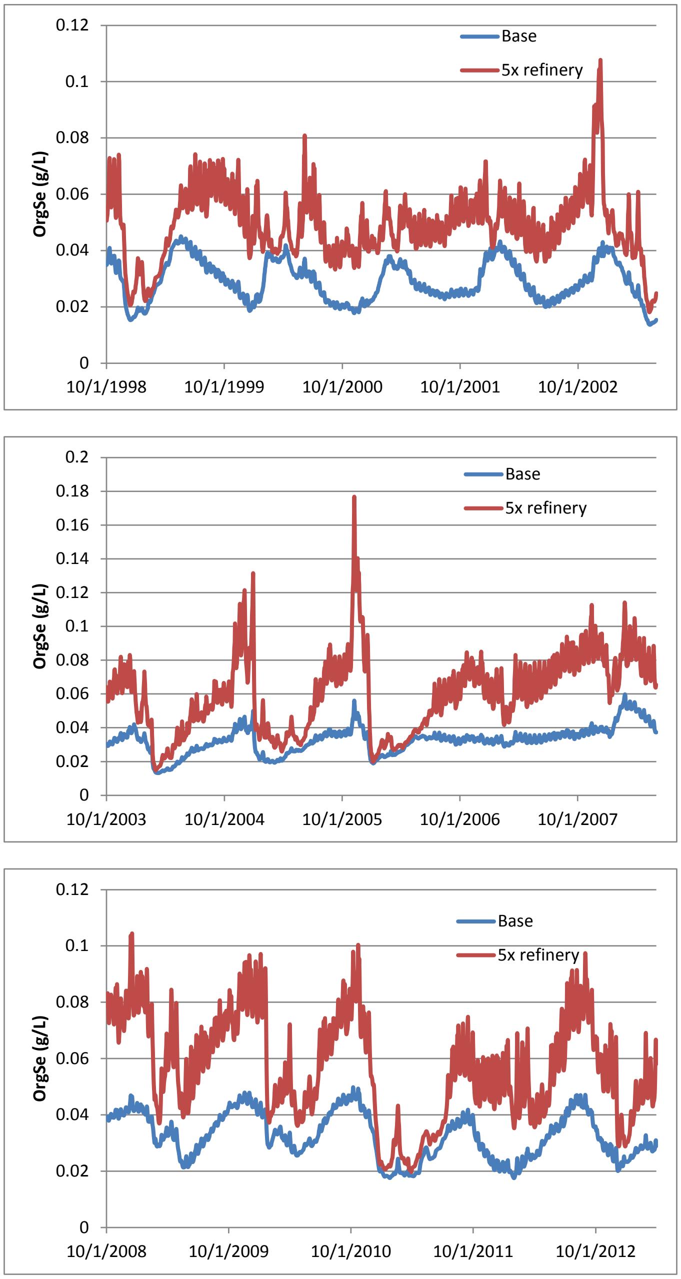


Figure 3-64
Simulated concentrations of organic selenide under current conditions and five times refinery load scenario at Carquinez Strait.

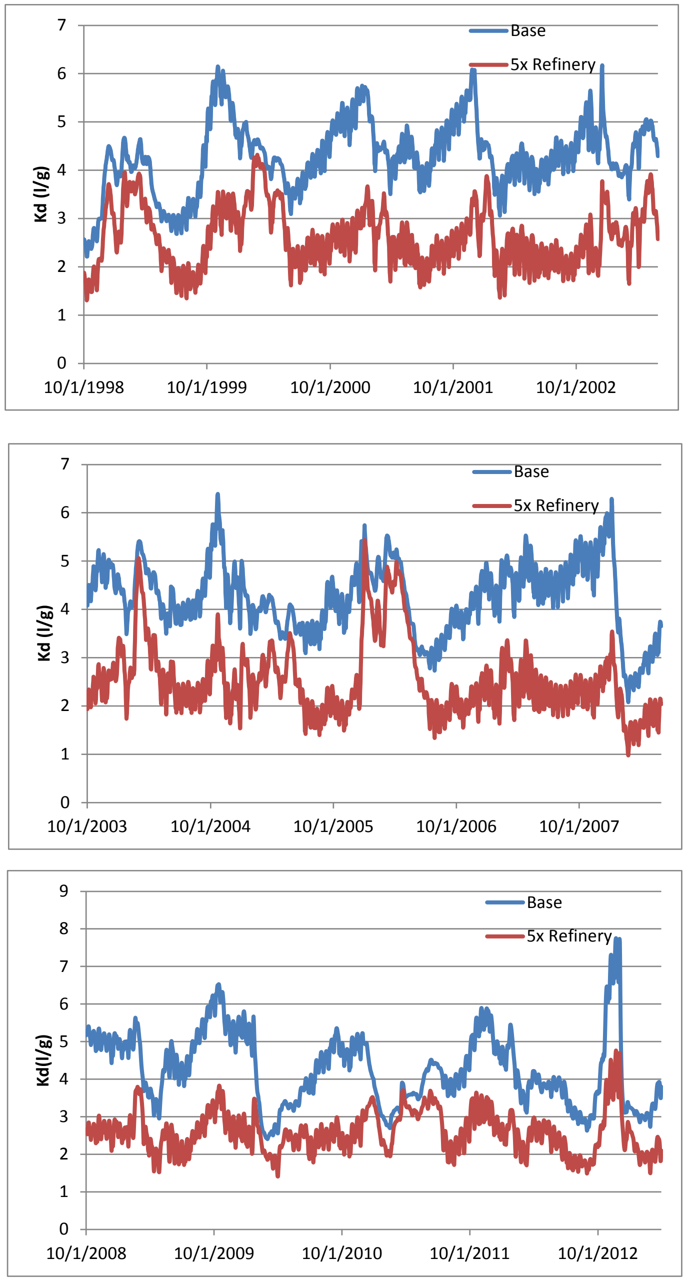


Figure 3-65
Simulated Kd under current conditions and five times refinery load scenario at Carquinez Strait.

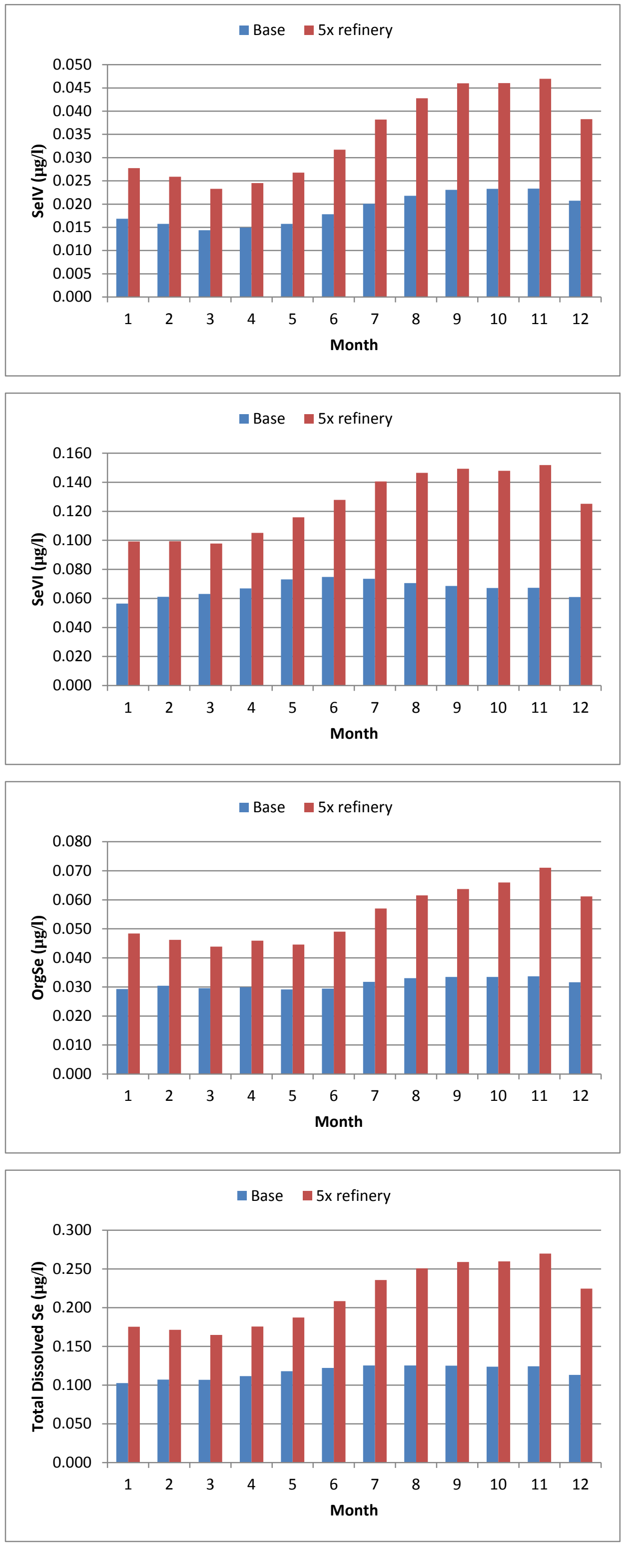


Figure 3-66
Simulated concentrations of dissolved selenium under current conditions and five times refinery load scenario at Carquinez Strait.

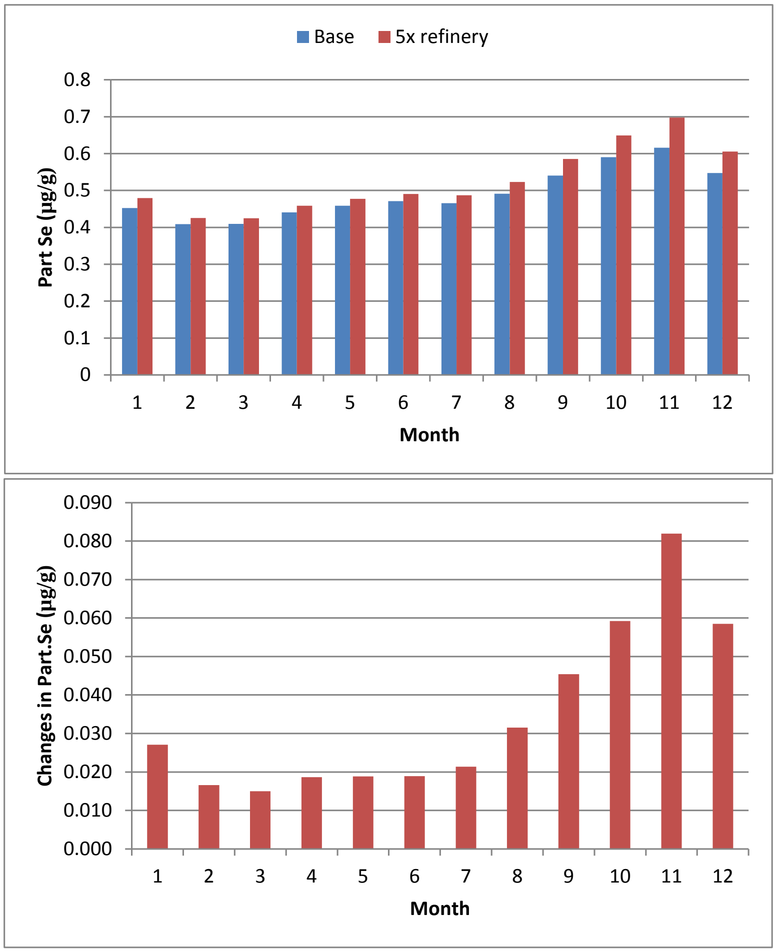
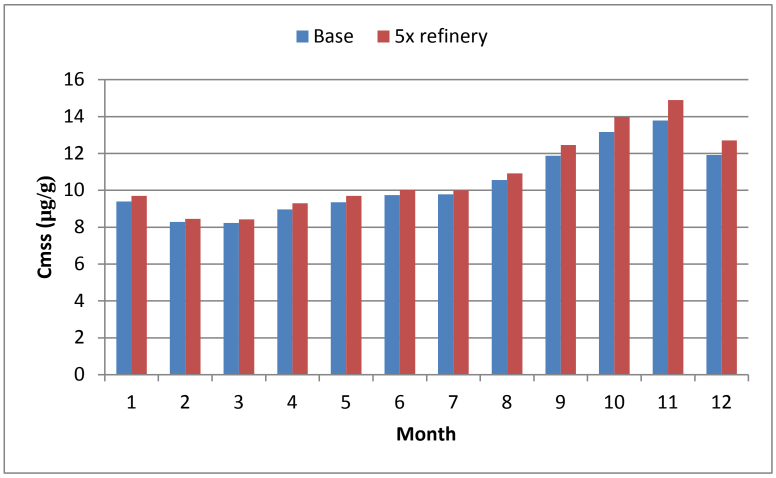


Figure 3-67
Simulated changes in particulate selenium due to five times refinery load scenario at Carquinez Strait.



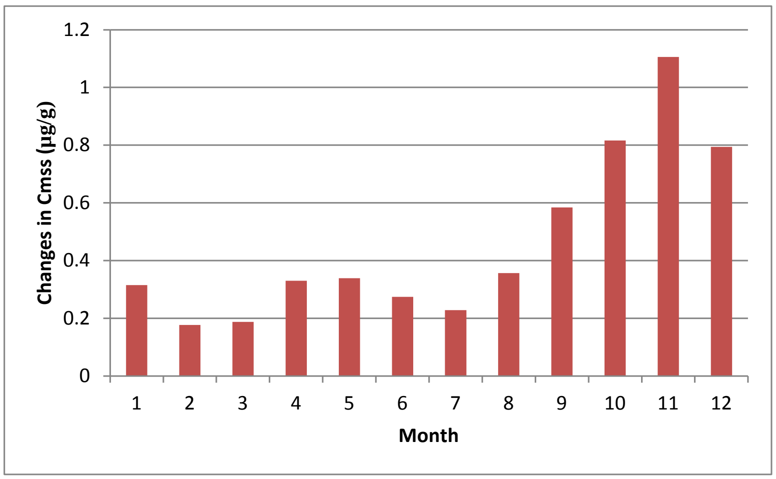


Figure 3-68
Simulated changes in clam selenium concentrations due to five times refinery load scenario at Carquinez Strait.

Table 3-16
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to five times refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Five times refinery	Change	Change (%)
Total Dissolved	0.091 (0.014 SeIV, 0.057 SeVI, 0.02 OrgSe)	0.145 (0.026 SeIV, 0.085 SeVI, 0.034 OrgSe)	0.054 (0.012 SeIV, 0.028 SeVI, 0.014 OrgSe)	59%
Total Particulate (µg/g)	0.563 (0.328 POrgSe, 0.118 PSeivvi, 0118 PSe0)	0.596 (0.348 POrgSe, 0.122 PSeivvi, 0.126 PSe0)	0.033 (0.02 POrgSe, 0.004 PSeivvi, 0.009 PSe0)	6%

Table 3-17
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to five times refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Five times refinery	Change	Change (%)
Total Dissolved	0.121 (0.02 SeIV, 0.07 SeVI, 0.03 OrgSe)	0.265 (0.048 SeIV, 0.152 SeVI, 0.065 OrgSe)	0.144 (0.025 SeIV, 0.082 SeVI, 0.037 OrgSe)	119%
Total Particulate (µg/g)	0.712 (0.490 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.840 (0.574 POrgSe, 0.138 PSeivvi, 0.128 PSe0)	0.128 (0.084 POrgSe, 0.012 PSeivvi, 0.032 PSe0)	18%

Table 3-18
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to five times refinery loads for Oct. 30, 1999 transect.

Species	Base Case	Five times refinery	Change	Change (%)
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.184 (0.038 SeIV, 0.105 SeVI, 0.041 OrgSe)	0.083 (0.047 SeIV, 0.017 SeVI, 0.019 OrgSe)	82%
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	1.011 (0.763 POrgSe, 0.141 PSeivvi, 0.108 PSe0)	0.139 (0.105 POrgSe, 0.009 PSeivvi, 0.025 PSe0)	16%

3.7 Effects of Increased SJR Flow

The effects of San Joaquin River flow increase were evaluated by increasing San Joaquin River flow at Antioch by 50% and modifying the selenium concentrations at boundary locations (Antioch and Rio Vista for the ECos model) due to increased SJR flow from Vernalis.

Figure 3-69 through Figure 3-72 show the results of increasing SJR flow at Antioch by 50% for the simulation period of 1998-2012. With increases in SJR flow at Antioch, selenite concentrations showed an increase of 0-0.003 µg/L during low flow. Selenate concentrations showed an increase of 0.002-0.041 µg/L, and organic selenide showed an increase of 0-0.006 µg/L. On a monthly average basis, selenite showed 0.001 µg/L increase for different months due to San Joaquin flow increase (Figure 3-73). Selenate showed an increase of 0.015 µg/L for different months. Organic selenide showed an increase of 0.002 µg/L.. Particulate selenium as a result showed monthly average changes of -0.01 – 0.11 µg/g for different months due to 50% increase in SJR flow (Figure 3-74). Selenium concentrations in clams showed a change of -0.2 to 3 µg/g for different months (Figure 3-75). The model simulated Kd (expressed as particulate selenium in µg/g over total dissolved selenium in µg/L) showed large seasonal and inter-annual variations.

The linkage between dissolved and particulate selenium was evaluated for a 50% increase in SJR flow scenario using the model at three locations: Suisun Bay, Carquinez Strait and San Pablo Bay for a dry period transect: Oct. 30, 1999.

At Suisun Bay, Carquinez Strait, and San Pablo Bay, the model simulated total dissolved selenium concentration is 0.091 µg/L, and was not changed much by increasing SJR flow (Table 3-19, Table 3-20, and Table 3-21). With increases in SJR flow, particulate selenium concentrations increased by 0.001, 0.006 and 0.006 µg/g in Suisun Bay, Carquinez Strait, and San Pablo Bay respectively.

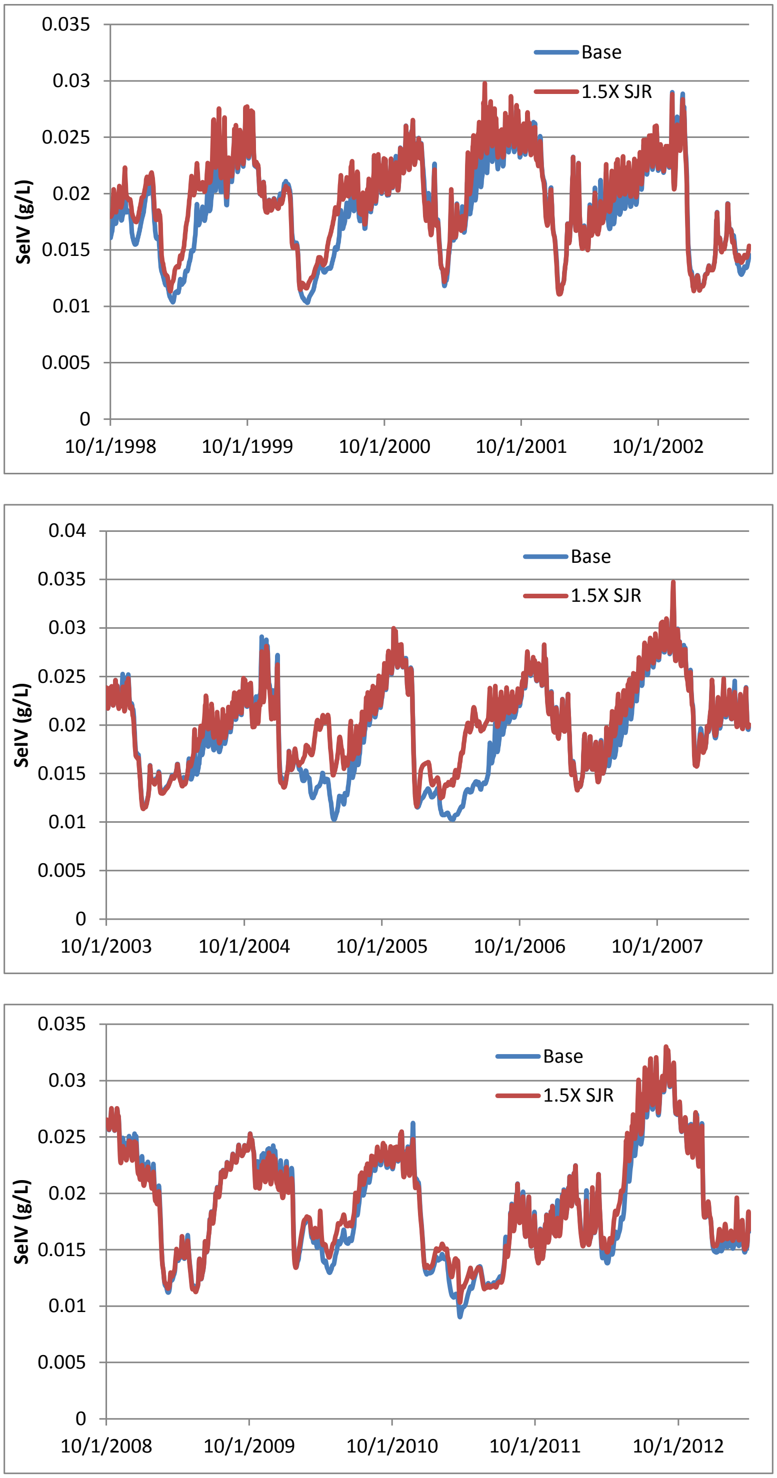


Figure 3-69
Simulated concentrations of selenite under current conditions and 50% increase in SJR flow scenario at Carquinez Strait.

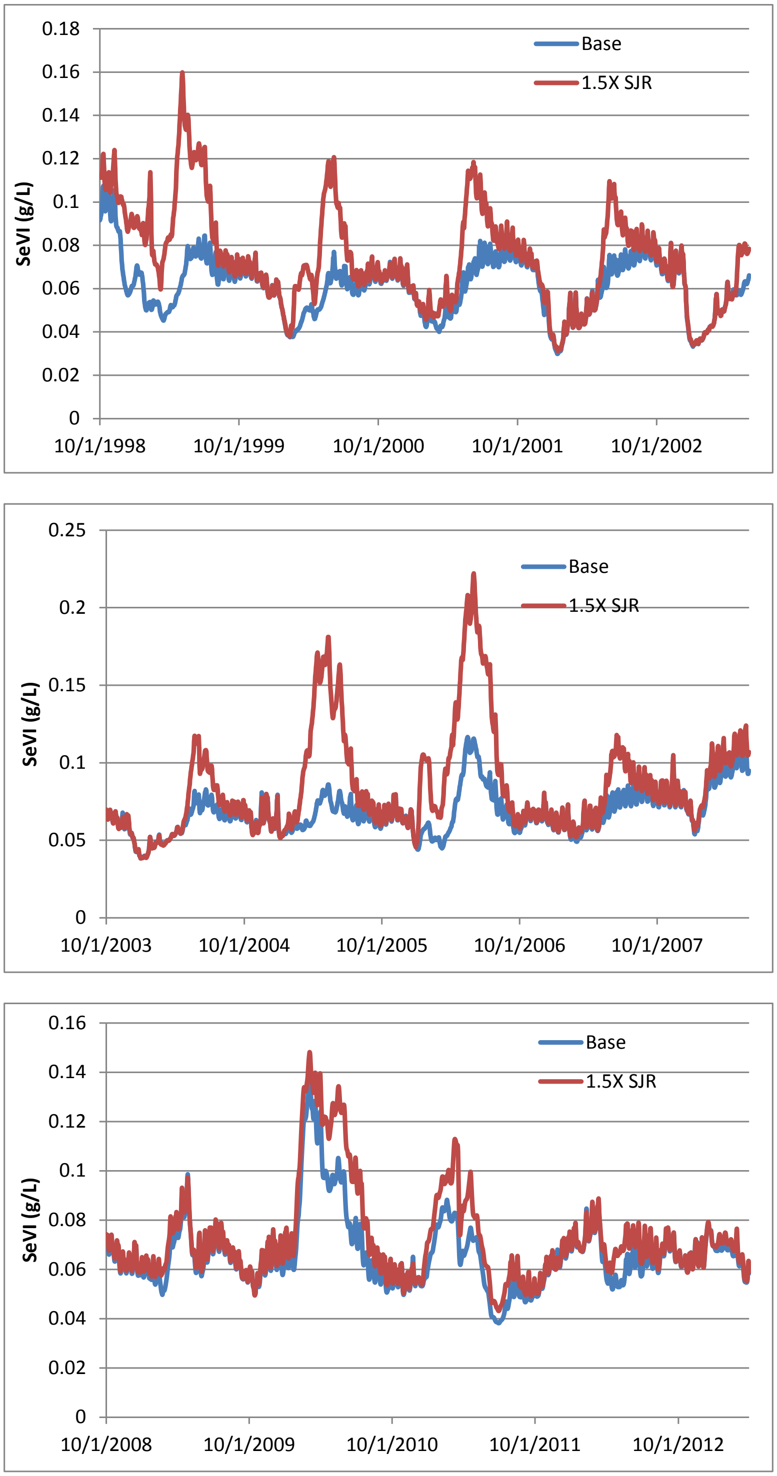


Figure 3-70
Simulated concentrations of selenate under current conditions and 50% increase in SJR flow scenario at Carquinez Strait.

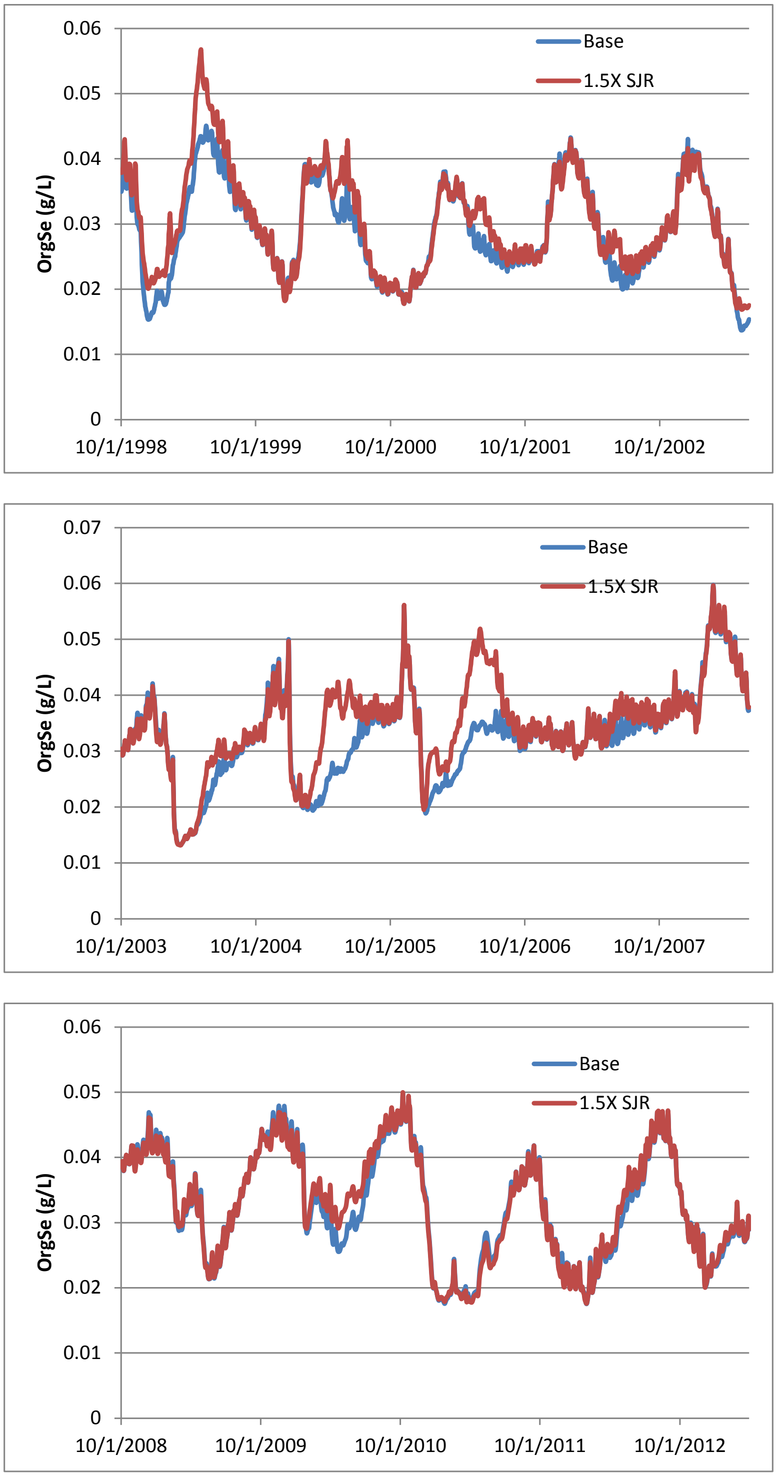


Figure 3-71
Simulated concentrations of organic selenide under current conditions and 50% increase in SJR flow scenario at Carquinez Strait.

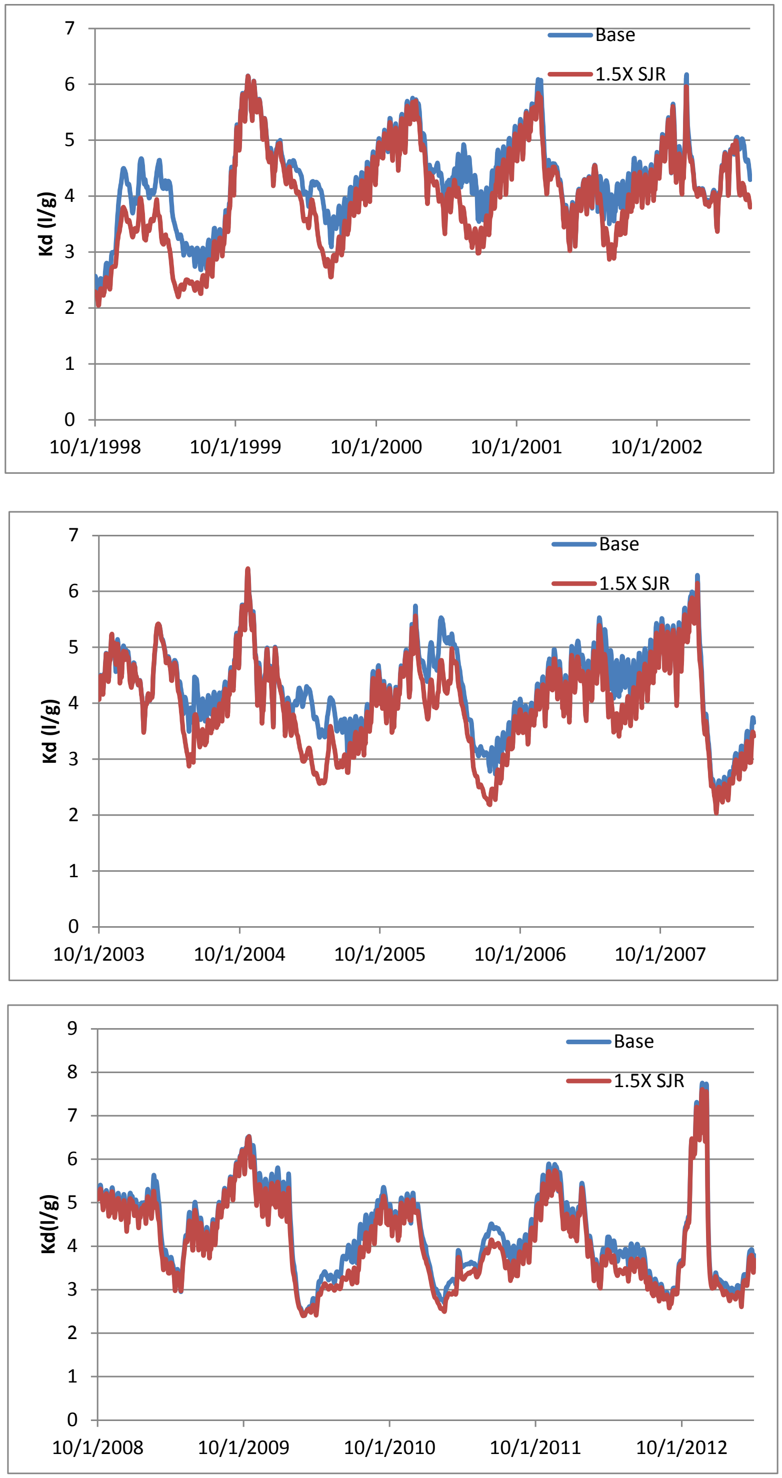


Figure 3-72
Simulated Kd under current conditions and 50% increase in SJR flow scenario at Carquinez Strait.

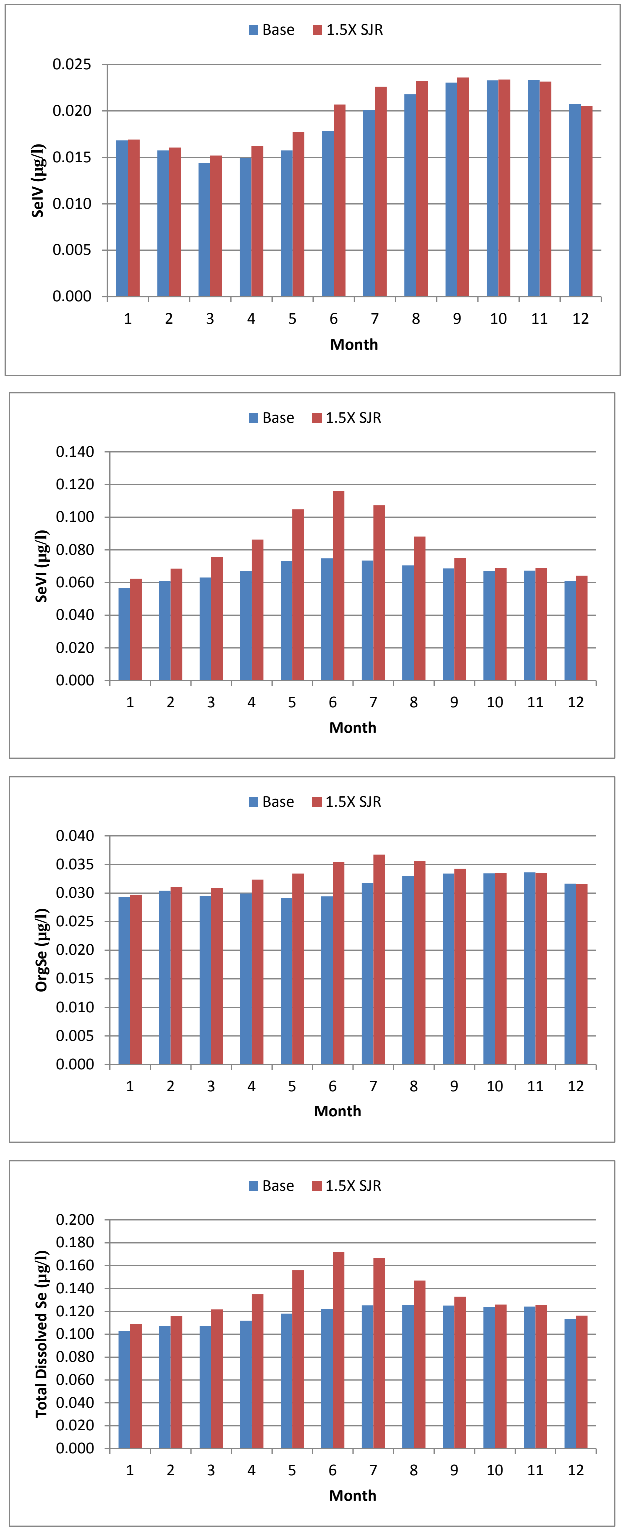


Figure 3-73
Simulated concentrations of dissolved selenium under current conditions and 50% increase in SJR flow scenario at Carquinez Strait.

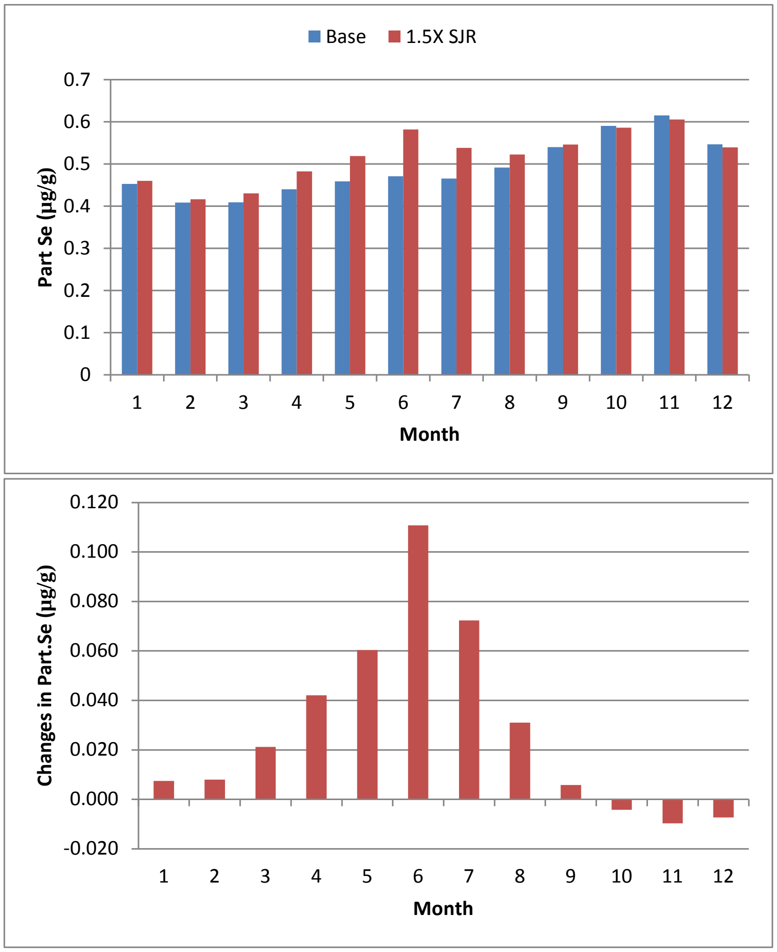


Figure 3-74
Simulated changes in particulate selenium due to 50% increase in SJR flow at Carquinez Strait.

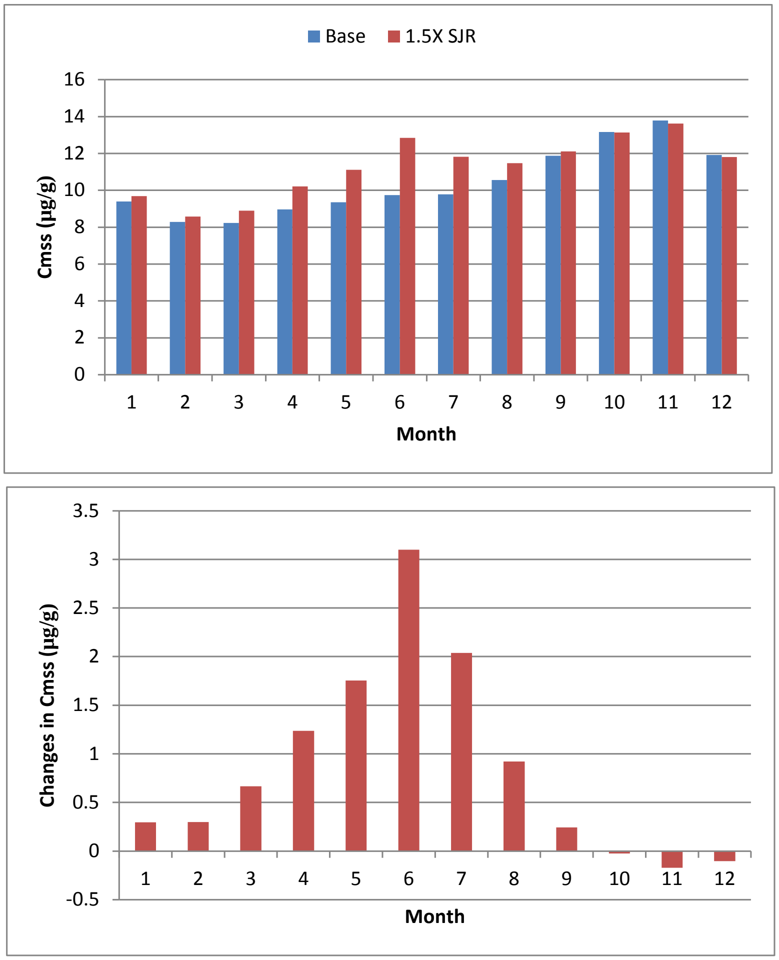


Figure 3-75
Simulated changes in clam selenium concentrations due to 50% increase in SJR flow at Carquinez Strait.

Table 3-19
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to 50% increase in SJR flow for Oct. 30, 1999 transect.

Species	Base Case	50% increase in SJR flow	Change
Total Dissolved	0.091 (0.0138 SeIV, 0.0571 SeVI, 0.02 OrgSe)	0.0919 (0.0139 SeIV, 0.0578SeVI, 0.02 OrgSe)	0.0008 (0.0001 SeIV, 0.0007 SeVI, 0.000 OrgSe)
Total Particulate (µg/g)	0.563 (0.328 POrgSe, 0.118 PSeivvi, 0118 PSe0)	0.564 (0.332 POrgSe, 0.118 PSeivvi, 0.115 PSe0)	0.001 (0.004 POrgSe, 0.000 PSeivvi, -0.003 PSe0)

Table 3-20
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to 50% increase in SJR flow for Oct. 30, 1999 transect.

Species	Base Case	50% increase in SJR flow	Change
Total Dissolved	0.121 (0.02 SeIV, 0.07 SeVI, 0.028 OrgSe)	0.1219 (0.022 SeIV, 0.071 SeVI, 0.028 OrgSe)	0.0009 (0.0000 SeIV, 0.0009 SeVI, 0.0000 OrgSe)
Total Particulate (µg/g)	0.7116 (0.490 POrgSe, 0.126 PSeivvi, 0.096 PSe0)	0.7172 (0.498 POrgSe, 0.126 PSeivvi, 0.094 PSe0)	0.006 (0.008 POrgSe, 0 PSeivvi, -0.002 PSe0)

Table 3-21
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to 50% increase in SJR flow for Oct. 30, 1999 transect.

Species	Base Case	50% increase in SJR flow	Change
Total Dissolved	0.101 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.1018 (0.021 SeIV, 0.058 SeVI, 0.022 OrgSe)	0.0007 (0.0001 SeIV, 0.0006 SeVI, 0.0001 OrgSe)
Total Particulate (µg/g)	0.872 (0.658 POrgSe, 0.132 PSeivvi, 0.083 PSe0)	0.8785 (0.664 POrgSe, 0.131 PSeivvi, 0.081 PSe0)	0.006 (0.008 POrgSe, 0 PSeivvi, -0.002 PSe0)

3.8 Natural Load Scenario

The natural load scenario was run by assuming: 1) all point sources are zero; 2) local tributary loads and speciation are set at Sacramento River values; and 3) the San Joaquin River is at 0.2 µg/l with current speciation. The results are shown here for time series of dissolved selenite, selenate, and organic selenide compared to base case (Figure 3-76- Figure 3-78) and for monthly average Kd values, dissolved selenium species and total dissolved selenium (Figure 3-79, Figure 3-80). The results suggest a lower dissolved selenium concentration of 0.02 – 0.04 µg/L for the natural load scenario. The results for particulate and clam selenium by month compared to base case are also shown (Figure 3-81and Figure 3-82). The results show slightly lower monthly particulate selenium of up to 0.02 µg/g for the natural load scenario. The results for a dry period (Oct 30, 1999) at three locations at Suisun Bay, Carquinez Strait and San Pablo Bay were also shown (Table 3-22 - Table 3-24). For the dry period, the results generally suggested a change in dissolved selenium of 0.02- 0.04 µg/l and 0.007-0.03 µg/g in particulate selenium at the three locations.

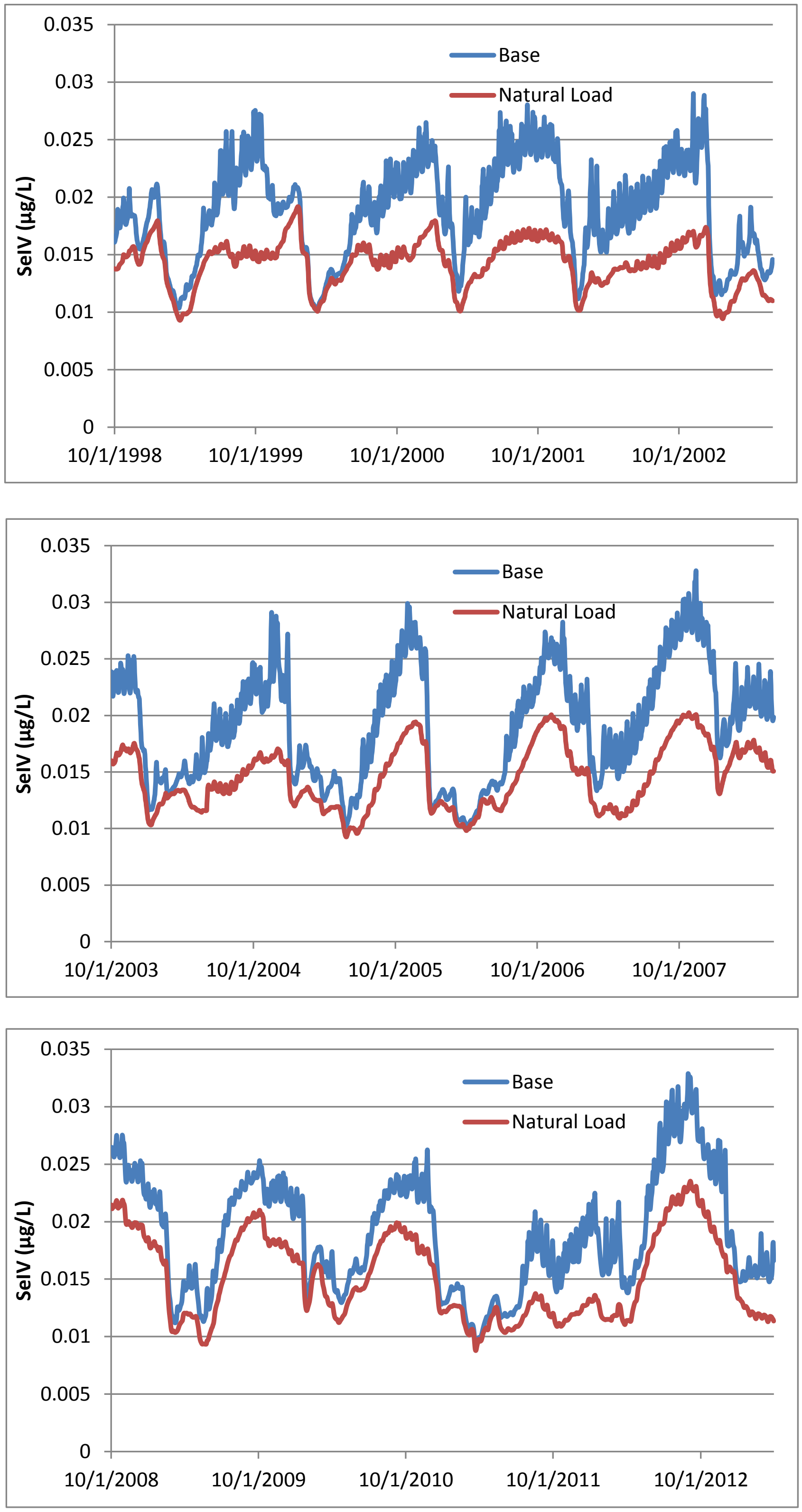


Figure 3-76
Simulated concentrations of selenite under current conditions and natural load scenario at Carquinez Strait.

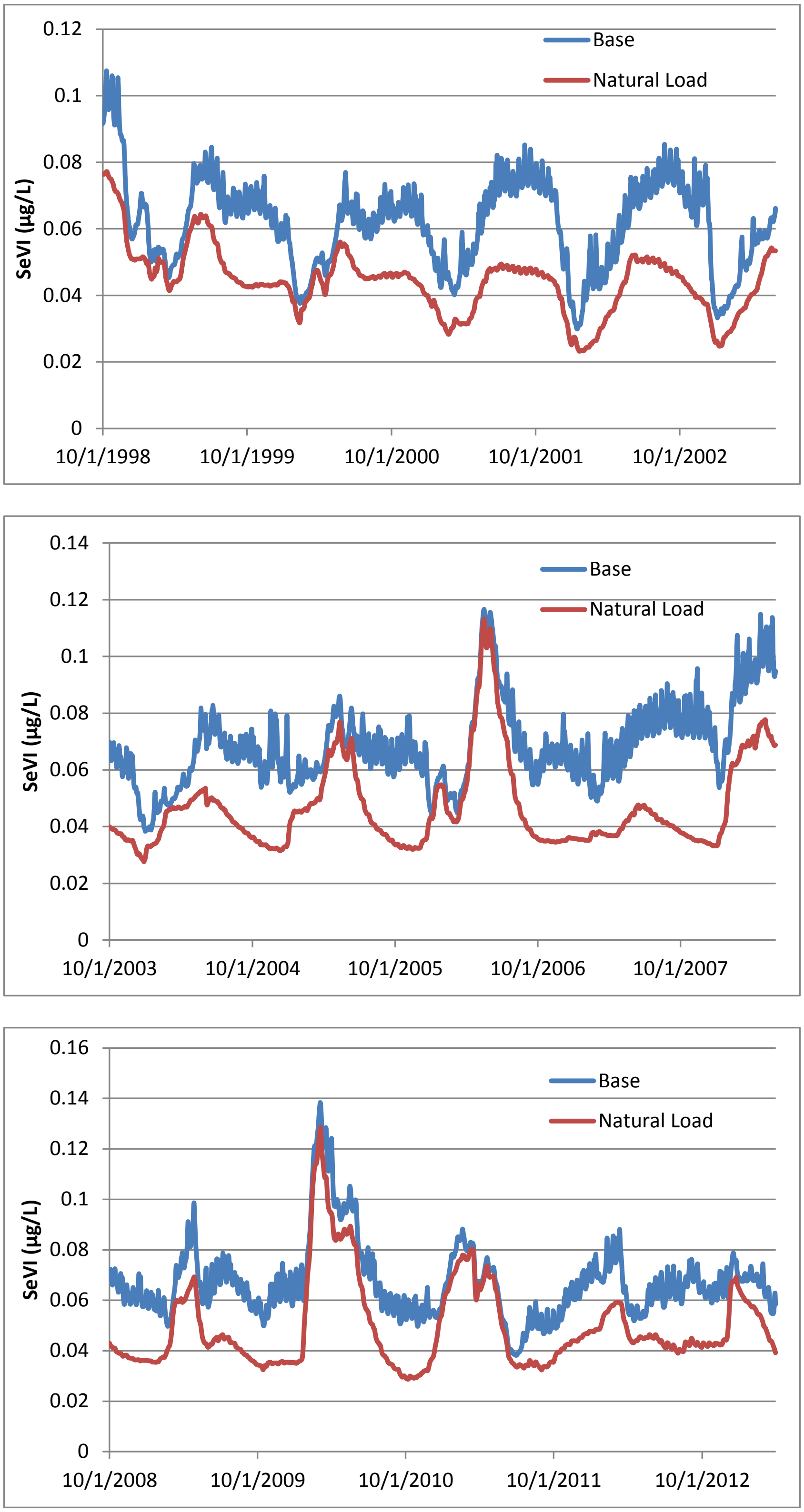


Figure 3-77
Simulated concentrations of selenate under current conditions and natural load scenario at Carquinez Strait.

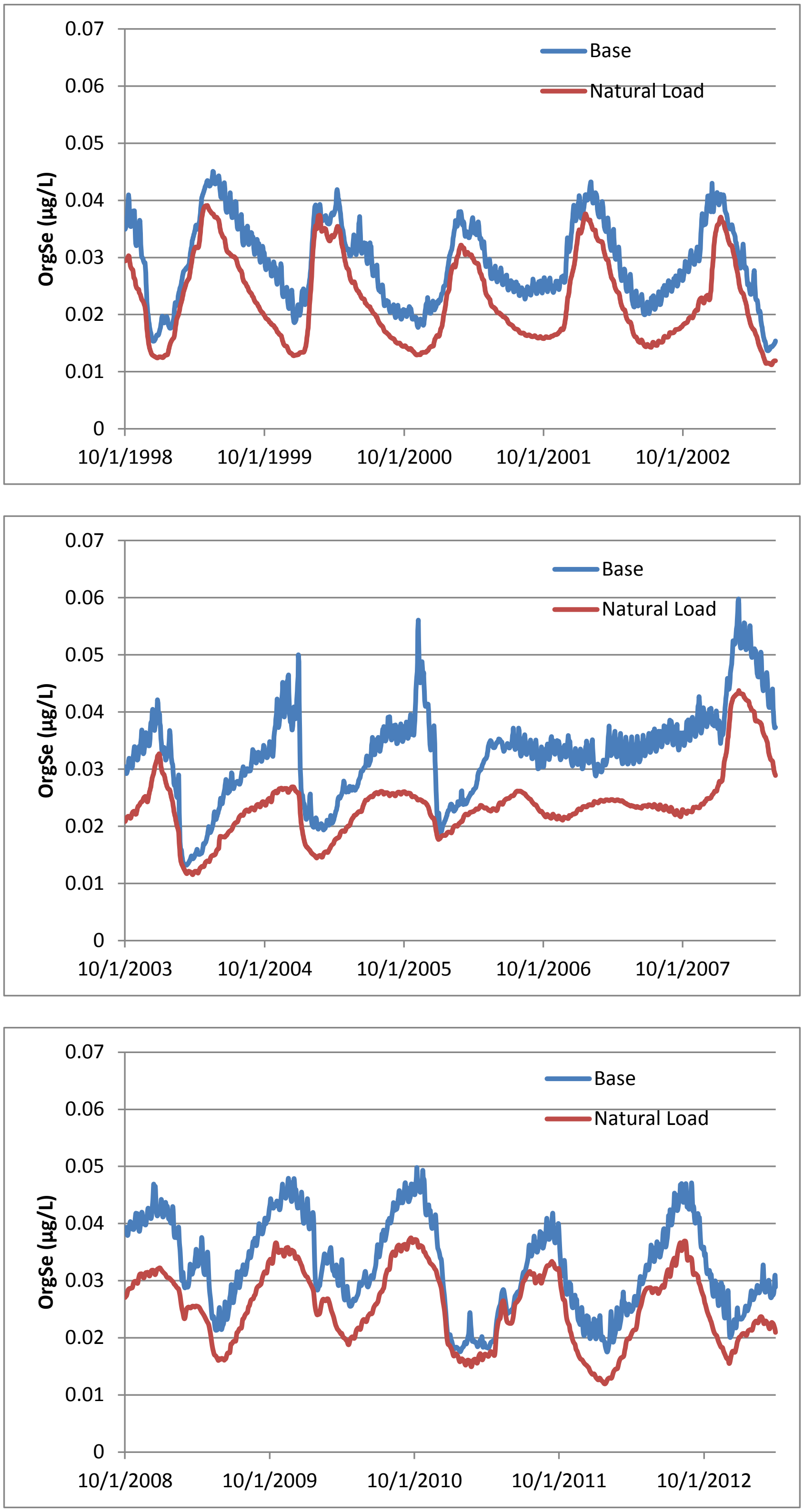


Figure 3-78
Simulated concentrations of organic selenide under current conditions and natural load scenario at Carquinez Strait.

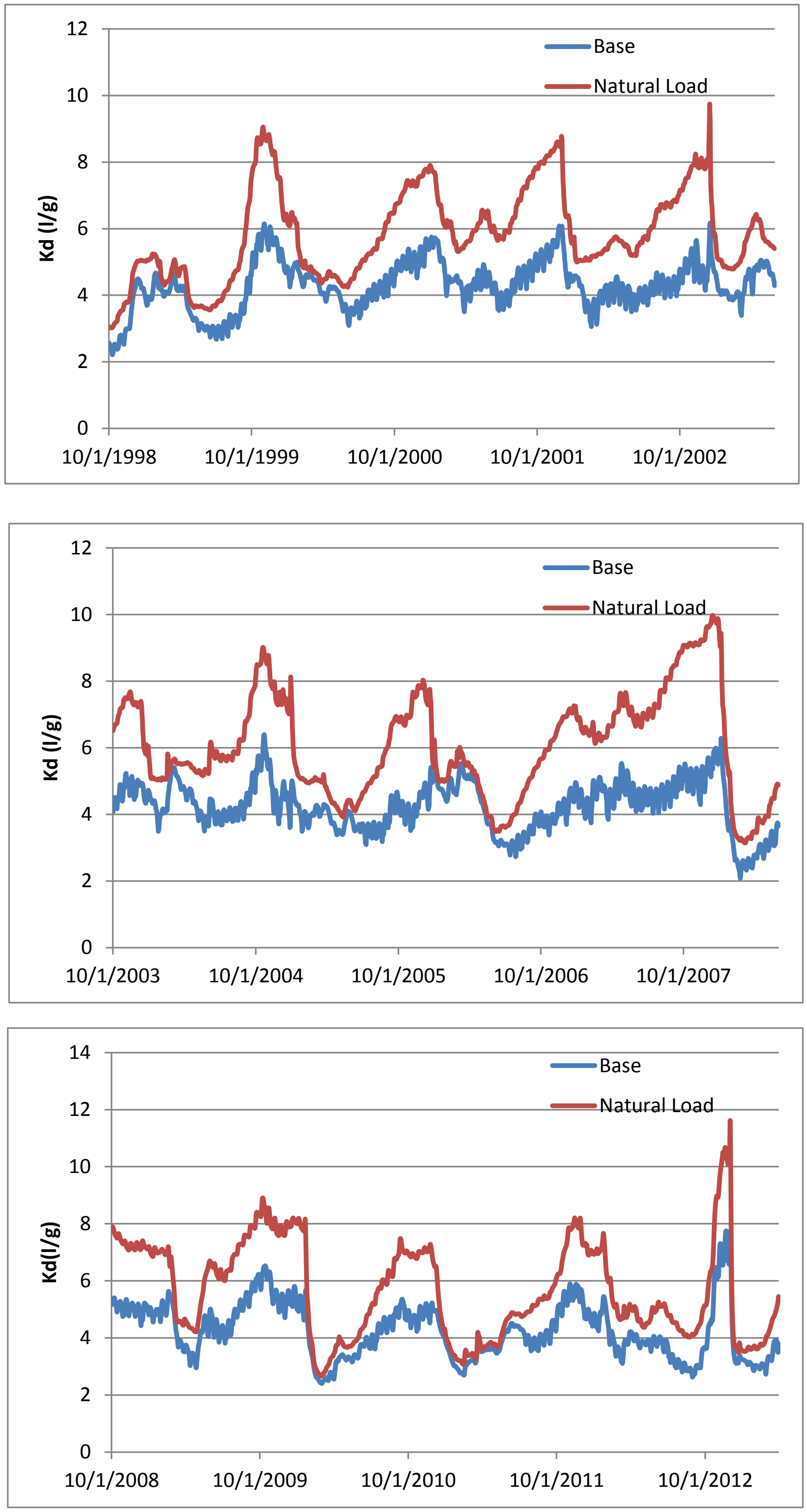


Figure 3-79
Simulated Kd under current conditions and natural load scenario at Carquinez Strait.

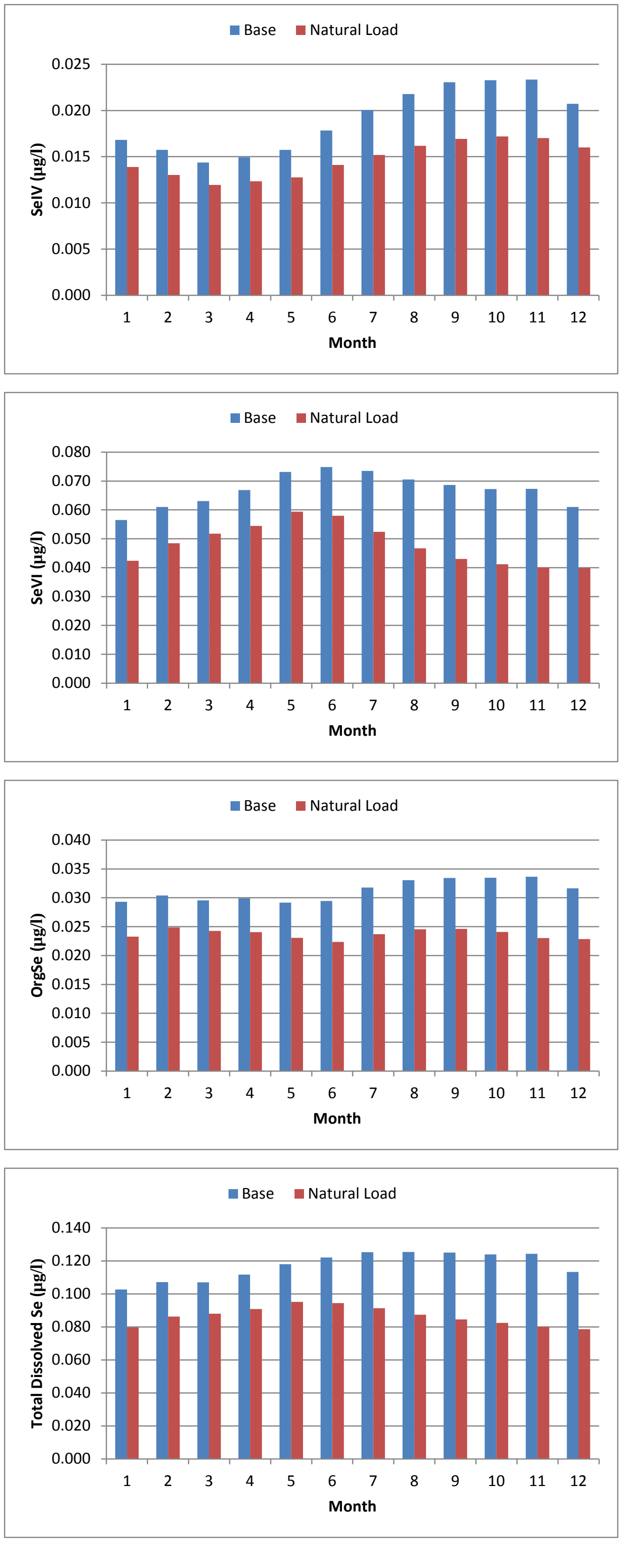


Figure 3-80
Simulated concentrations of dissolved selenium under current conditions and natural load scenario at Carquinez Strait.

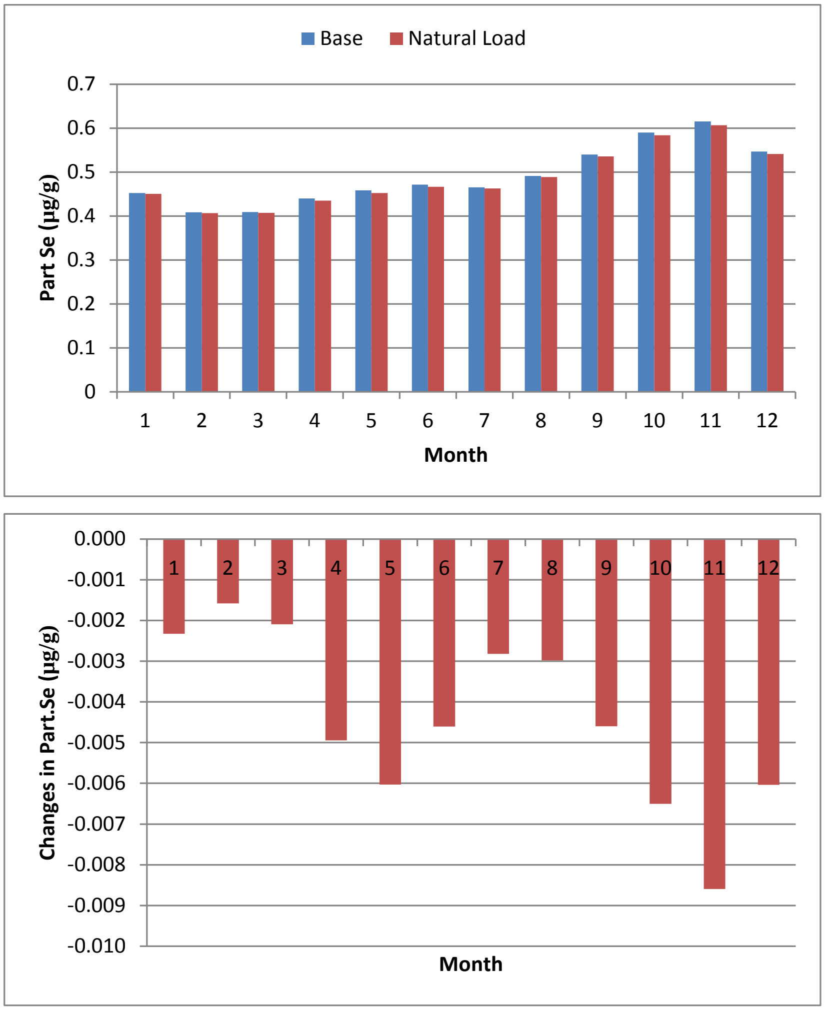


Figure 3-81
Simulated changes in particulate selenium due to natural loads at Carquinez Strait.

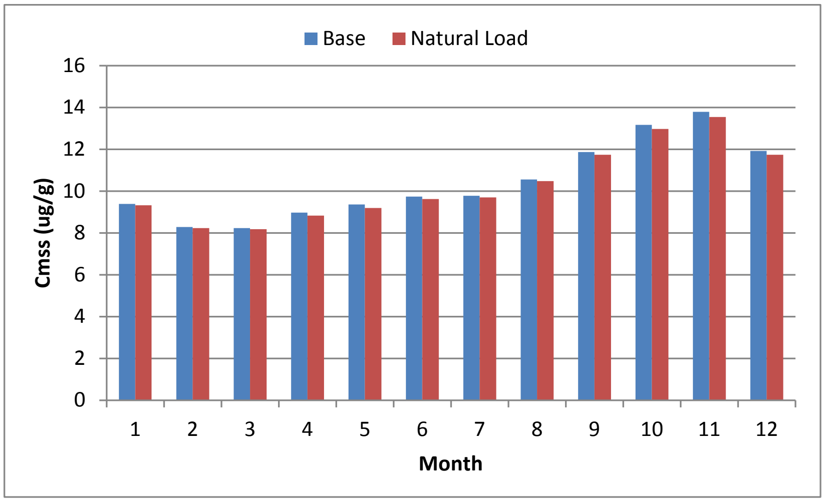


Figure 3-82
Simulated changes in clam selenium concentrations due to natural loads at Carquinez Strait.

Table 3-22
Changes in dissolved and particulate selenium concentrations in Suisun Bay due to natural loads for Oct. 30, 1999 transect.

Species	Base Case	Natural load	Change
Total Dissolved	0.091	0.070	0.021
Total Particulate (µg/g)	0.563	0.557	0.006

Table 3-23
Changes in dissolved and particulate selenium concentrations in Carquinez Strait due to natural loads for Oct. 30, 1999 transect.

Species	Base Case	Natural load	Change
Total Dissolved	0.121	0.076	0.045
Total Particulate (µg/g)	0.712	0.686	0.025

Table 3-24
Changes in dissolved and particulate selenium concentrations in San Pablo Bay due to natural loads for Oct. 30, 1999 transect.

Species	Base Case	Natural load	Change
Total Dissolved	0.101	0.075	0.026
Total Particulate (µg/g)	0.872	0.841	0.031

3.9 Relating Modeling Results to Assimilative Capacity

The modeling results over a range of increased and decreased loading scenarios provides insight into the assimilative capacity of North San Francisco Bay for selenium, which is largely based on the concentration of biologically available selenium in particulate form. Thus, particulate selenium has the potential to bioaccumulate in clams and into predator organisms that largely feed on benthic species. The model calculations show that as loads increase or decrease there are significant changes in the dissolved concentrations, but considerably more muted changes in the particulate concentrations. When the refinery loads are increased by a factor of two or five, the total dissolved selenium concentrations at Carquinez Strait increase by 30% and 119% respectively. In comparison, the particulate selenium concentrations increase by 4.5% and 18%. Likewise, when concentrations are decreased by removing all major sources, dissolved selenium concentrations decrease by 51.2%, and particulate selenium concentrations decrease by 6.3%.

The reason for the limited change in particulate selenium despite these large shifts in loads is related to the calibrated selenium uptake and release rates from the particulate phase. These calibrated rates are constrained by the observed data on dissolved and particulate species in the transects; should the uptake rates be much higher the modeled distribution between the dissolved and particulate phases would not match the observations. Overall, the uptake/release rates and residence times in the Bay are such that the particulate response is much smaller than the response in the dissolved phase concentrations. At another extreme in the model formulation, if the particulate concentrations were in some form of pseudo-equilibrium with the dissolved phase, i.e., represented through a partitioning type coefficient (like a Kd), the percentage change in particulate concentrations would be identical to that in the dissolved phase concentrations. The observed data are supportive of a rate-limited, rather than an equilibrium-type relationship. Specifically, there are seasonal shifts in particulate concentrations with no similar changes in dissolved concentrations as would be expected if an equilibrium-type relationship were applicable.

The modeling results demonstrate that there is a relationship between selenium in dissolved and biologically available forms (particulate selenium), but it is not a one-to-one response. The system is resilient to shifts in particulate selenium, for both load increases or decreases. At one level, the uptake/release and estuary residence time effects, can be thought of as providing some level of assimilation capacity, in that an extra level of loading or dissolved selenium is mostly transported out of the bay before it is transformed into a biologically available form. In the most extreme case considered above, an increase of refinery loads by a factor of five is calculated to show an increase of 18% in the particulate selenium at Carquinez Strait. There are no proposals for increasing the point-source loads of selenium into the Bay, although the modeling suggests that small increases in the dissolved concentrations would have a limited effect on particulate selenium.

4 Summary

This memorandum summarizes the application of an estuary model for simulating selenium dynamics within the NSFB, updated using the most recent selenium loading and estuary transect data. Specifically, recent estuary transect data were combined with corresponding selenium data from all important bay sources and from the Delta using the DSM2 model, to better characterize current selenium loads and the estuary concentrations.

Key findings from the modeling update are as follows:

- With concentration and speciation data collected for refineries and tributaries from recent sampling, the model is able to simulate the patterns in multiple dissolved selenium species, although there are occasions where dissolved selenium is slightly under-predicted. This improved fit can be largely attributed to better loading data because the published transformation rates (Chen et al., 2012) did not need to be modified.
- The particulate selenium species, of particular importance to the linkage analysis with biota, can be simulated by the model (detailed plots in Appendix A). However, due to simplifications inherent in the scale of the current model formulation, local variations in particulate selenium are not always captured. For example, they may be caused by local variations in phytoplankton growth that are not represented in the model. However, the spatial patterns of particulate selenium (in µg/g) under different flow conditions can be simulated reasonably well.
- With the updated model inputs and largely unchanged selenium transformation rates, the model is also able to simulate selenium dynamics in the historical time periods (April and November 1999).

The following observations are of relevance to the development of the selenium TMDL:

- Taken together, the model simulation of current conditions was used as a basis to explore the removal of specific sources from the bay (refineries, rivers, tributaries and other sources).
- Currently, model simulated dissolved selenium at Carquinez Strait is approximately 0.13 µg/L during the dry periods, with 0.03-0.036 µg/L coming from the refineries. Of this, more than 50% is selenate. Uptake of refinery inputs of dissolved selenium contributes about 0.02 µg/g of particulate selenium at Carquinez Strait, about 3% of the baseline level.
- When refinery loads were reduced to zero, total dissolved selenium concentrations decreased by 29.8% , and total particulate concentrations by 3.0%.
- When riverine loads were reduced to zero, but refinery loads were included at their baseline levels, total dissolved selenium concentrations decreased by 21.5% , and total particulate concentrations by 3.2%.
- When all riverine, tributary, and point source loads were reduced to zero, total dissolved selenium concentrations decreased by 51.2 % , and total particulate concentrations by 6.3%.

- Additional scenarios, i.e., a 50% reduction in refinery loads and a 50% increase in San Joaquin River flows, show related behavior: a response in the dissolved concentrations and limited change in particulate concentrations.
- In general, upon reduction of the major dissolved selenium sources, there are reductions in the bay dissolved concentrations. However, given the calibrated particulate uptake/release rates, there is only a modest change in the particulate concentrations. Thus, the calculated Kd values show an increase as a result of major load reductions. This is an important finding and shows that Kd values are not uniform in the presence of large changes in loads.
- When all dissolved loads are reduced to zero (riverine, local tributaries, and point sources), the typical water column selenium concentrations in the bay are reflective of the ocean boundary.
- The model shows a similar sensitivity to increased point-source loads for dissolved and particulate selenium, i.e., clear response for dissolved selenium and muted response for particulate selenium. When the refinery loads are increased by a factor of two or five, the total dissolved selenium concentrations at Carquinez Strait increase by 30% and 119% respectively. In comparison, the particulate selenium concentrations increase by 4.5% and 18%. Likewise, when concentrations are decreased by removing all major sources, dissolved selenium concentrations decrease by 51.2%, and particulate selenium concentrations decrease by 6.3%.
- The model represents current understanding of the bay system and selenium transformation processes. The reason for the limited change in particulate selenium despite these large shifts in loads is related to selenium uptake and release rates from the particulate phase that are calibrated values. Overall, the uptake/release rates and residence times in the Bay are such that the particulate response is much smaller than the response in the dissolved phase concentrations. Much longer residence times or higher uptake rates would result in greater changes in particulate phase. However, the residence time is a property of the estuary and its freshwater flows, and the accuracy of estimated reaction rates is determined by the available observations of dissolved and particulate selenium through representative transect data collected from 1999 through 2012.

Going forward, the model appears to be an effective representation of selenium biogeochemistry in the bay, and can serve to mechanistically evaluate the effects of significant changes in the system, such as the modification of major loads, or the effects of different hydrologic conditions and seasonal effects.

Despite more than a decade of monitoring and modeling efforts, and the strengths of the past efforts, there remain uncertainties associated with the model and inputs that should be evaluated in future work and in the potential application of the current model:

- Selenium inputs from the rivers (Sacramento and San Joaquin River) are the dominant sources of selenium to the Bay, but there is limited information at these riverine locations Only a few data points are available from the four transect sampling events and monthly data for the past seven years. This limited information results in challenges in applying the model over a longer time period. Limited data are available to parameterize speciation of dissolved selenium from the riverine inputs, and no speciation data are available to parameterize selenium speciation for the period of 2000-2010. Future work may incorporate more frequent sampling at the boundaries, particularly at the main input locations of Sacramento River at Freeport and San Joaquin River at Vernalis.

- The transformation of selenium from sources to the Delta and within the Delta remains uncertain. Although the use of the DSM2 model better represents mixing of flow at Rio Vista and at the confluence of the two rivers, actual observations are limited. Potential transformations may exist within Delta that affect the quantity and speciation of selenium before transport to the bay, and have not been characterized through field observations.
- Future study may require better representation of phytoplankton dynamics in the model and a spatially variable sediment re-suspension routine, to possibly address some of the local variations noted in the data.

5 References

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USGS. 2014. National Water Information System: Web Interface. USGS 11303500 SAN JOAQUIN R NR VERNALIS CA (URL: *http://waterdata.usgs.gov/ca/nwis/uv?cb_00010=on&cb_00060=on&cb_00065=on&format=html&period=7&site_no=11303500)*

A Appendix: Model Calibration

A.1 Simulation for the 2010 – 2012 Transects

Model-simulated physical parameters (salinity, TSM and chlorophyll a), dissolved selenium (selenite, selenate, and organic selenide) and particulate selenium species for the four sampling transects during 2010-2012 were compared to observed values (Figure A-1 through Figure A-16). In some cases, when data from transect sampling were missing, data from USGS bay cruise sampling from proximal sampling dates were used for comparison. Statistical measurements of model performance for each variable are shown in Table A-1 through Table A-4.

Fall 2010 Transect

The model-simulated salinity for the four transects generally agreed with the observed values. The 2010 dry season sampling showed a different pattern from the normal TSM profile existing in the bay and from the USGS sampling data, therefore this pattern in TSM was not captured by the model. The phytoplankton concentrations for the fall 2010 sampling were lower than the USGS sampling data, however the model was calibrated to the lower values from the sampling (Figure A-1).

For the 2010 dry season sampling, the dissolved selenium species generally showed a peak in the mid- estuary, and this pattern was captured by the model (Figure A-2). The particulate selenium species showed somewhat larger variations than the model predicted values, although in general the model predicted values are in the range of the observed values (Figure A-3). Some local variations in particulate organic selenium are not captured by the model, and are most likely due to local variations in phytoplankton concentrations and species. The model-simulated total particulate selenium (in µg/g) showed some over-predictions at higher salinities (Figure A-4); this is mainly due to the mismatch in TSM profile.

The model performance for the 2010 dry season transect measured by the goodness of fit (GOF) is relatively high, generally greater than 85% for salinity and dissolved selenium species (Table A-1). The percent bias (PBIAS) is generally less than 15%. Phytoplankton and particulate selenium species, due to some local variations not captured by the model, generally showed larger percent bias and lower goodness of fit.

Spring 2011 Transect

The spring 2011 sampling showed an increase in TSM toward Golden Gate (Figure A-5). This pattern is somewhat captured by the model. The model is able to predict a similar estuarine turbidity maximum (ETM), although at an upper estuary location. The phytoplankton concentrations for the spring 2011 sampling showed elevated levels at the head of estuary and the lower estuary. Due to lower temperature and solar radiation, the simulated phytoplankton is generally low during March and therefore the bloom event was not captured by the model.

For the spring 2011 sampling, the dissolved selenium species generally showed conservative behavior in the estuary, and this pattern is well captured by the model (Figure A-6). Selenite concentrations showed some under-prediction by the model. The under-prediction is most likely due to uncertainties in dissolved selenium inputs and speciation from the rivers. The GOF was greater than 92% for dissolved selenium species (Table A-2). The particulate selenium species are generally predicted well by the model (Figure A-7). The particulate elemental selenium showed low concentrations (non-detect) during this high flow sampling event. This species is slightly over-predicted by the model. In general, total particulate selenium (in µg/g) is predicted well by the model, except the high values associated with phytoplankton bloom at the head of estuary (Figure A-8), with GOF of 50%.

The model performance for the spring 2011 transect measured by GOF is relatively high, with GOF values generally greater than 75% for salinity and dissolved selenium species (Table A-2). The percent bias (PBIAS) is generally less than 15%. Phytoplankton and particulate selenium species, due to some local variations not captured by the model, generally showed larger percent bias and lower goodness of fit.

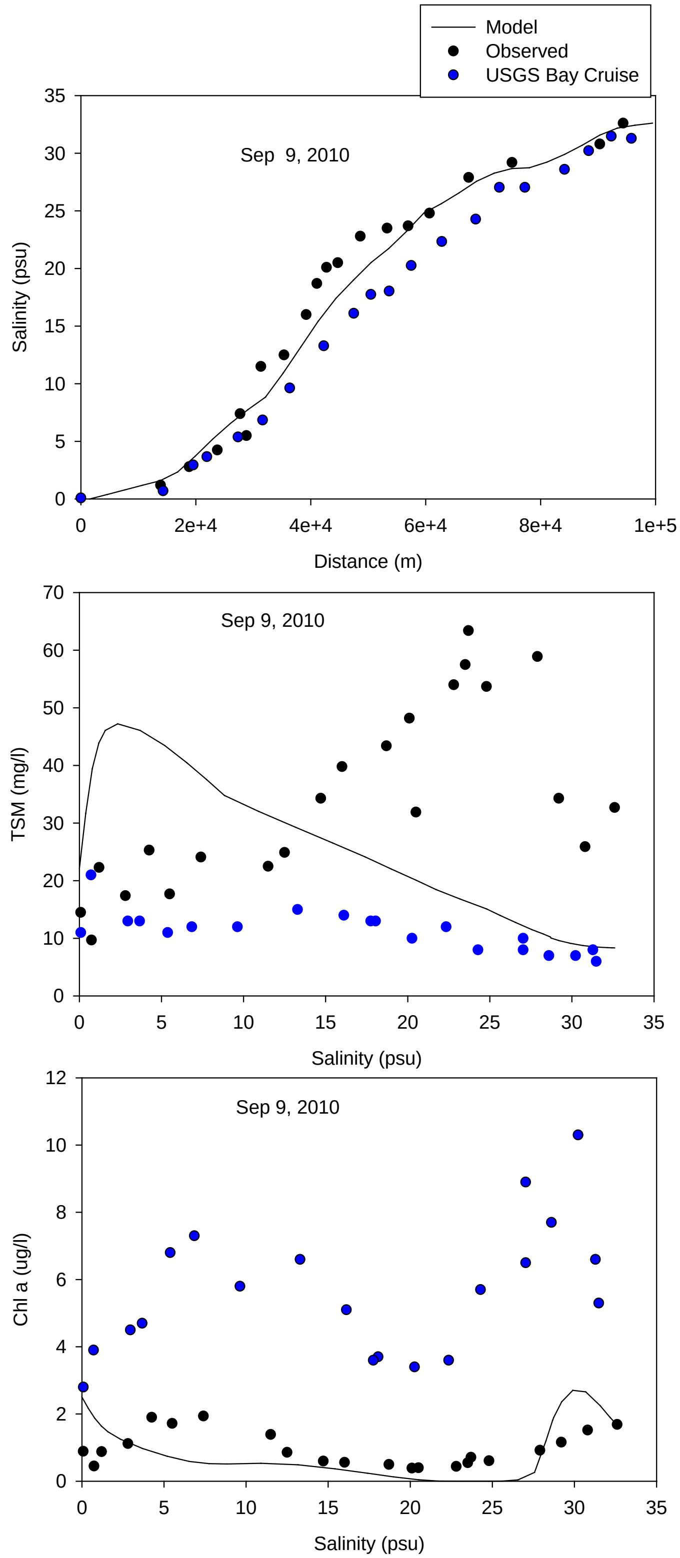

Figure A-1
Model simulated salinity, TSM, and Chlorophyll a compared to observed values for the 2010 dry season transect.

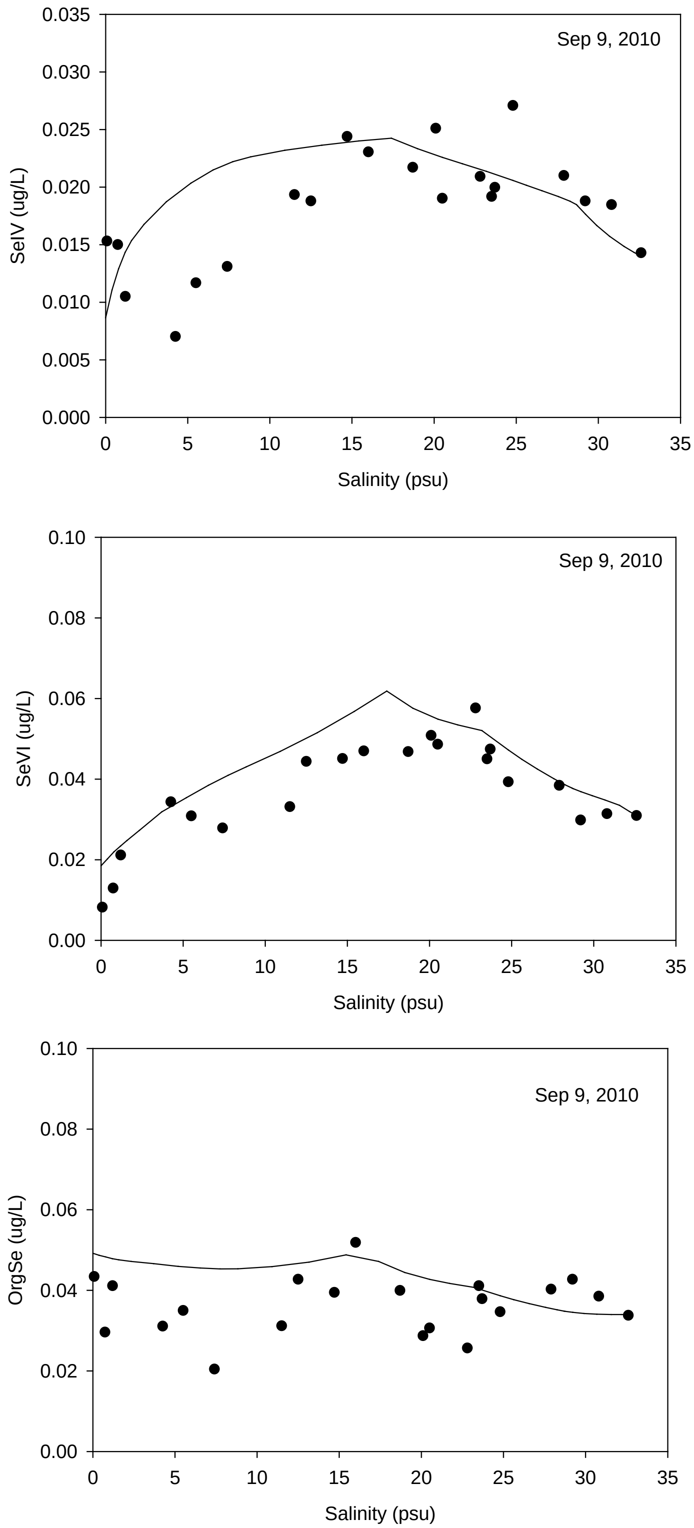

Figure A-2
Model simulated selenite, selenate and organic selenide compared to observed values for the 2010 dry season transect.

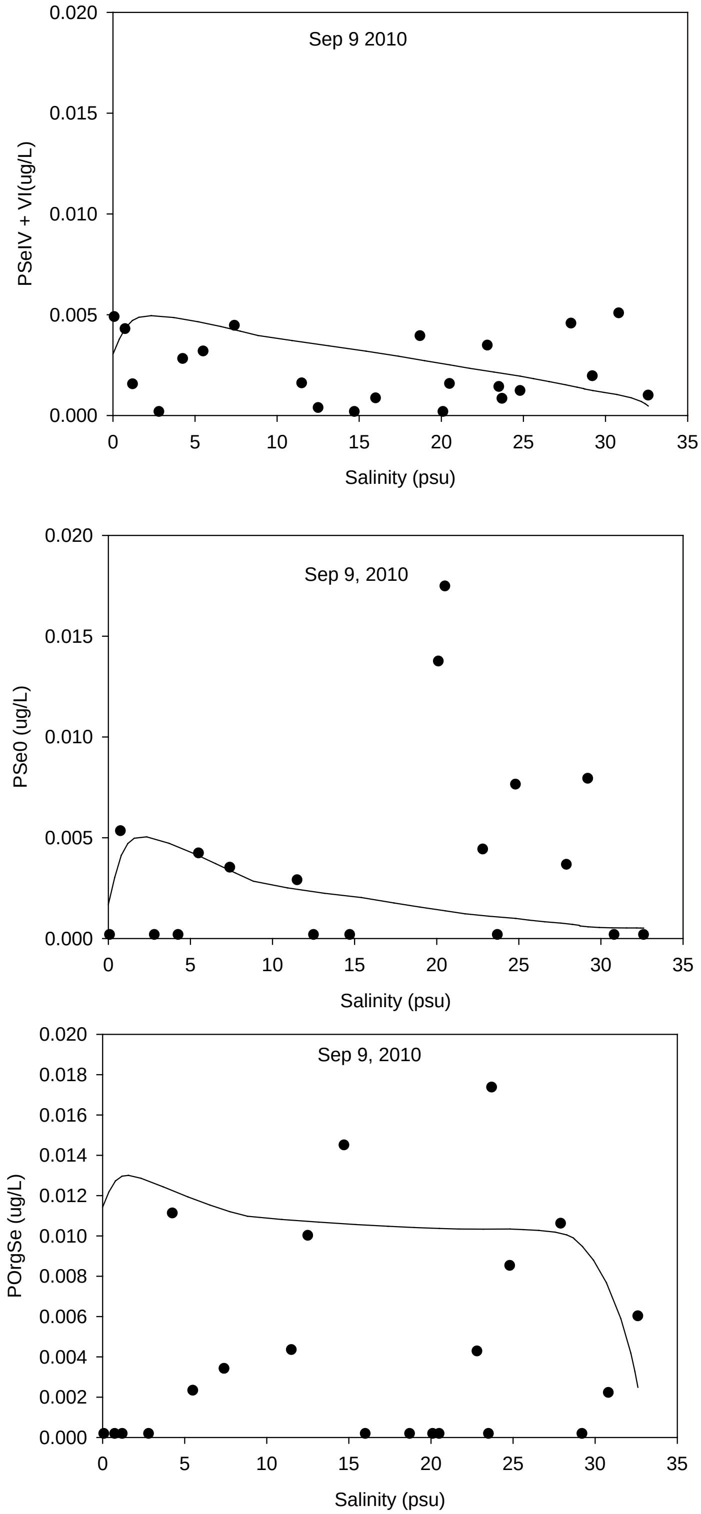

Figure A-3
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values for the 2010 dry season transect.

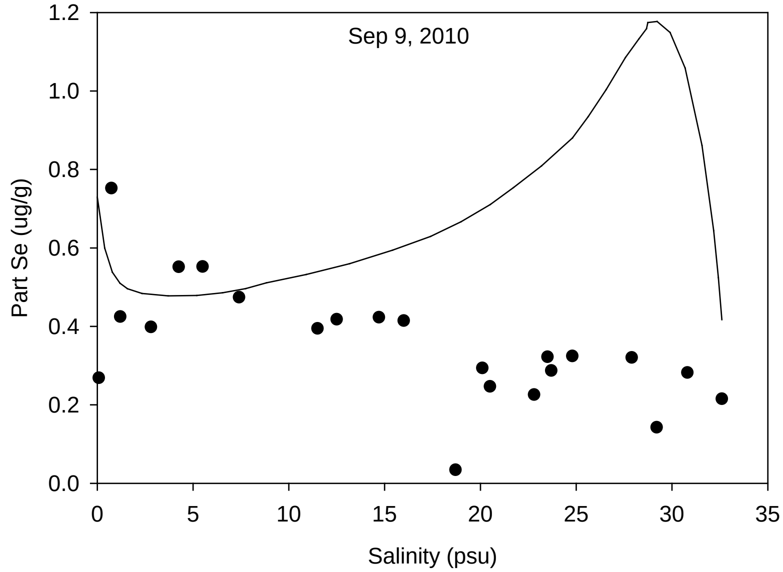

Figure A-4
Model simulated particulate selenium (in µg/g) compared to observed values for the 2010 dry season transect.

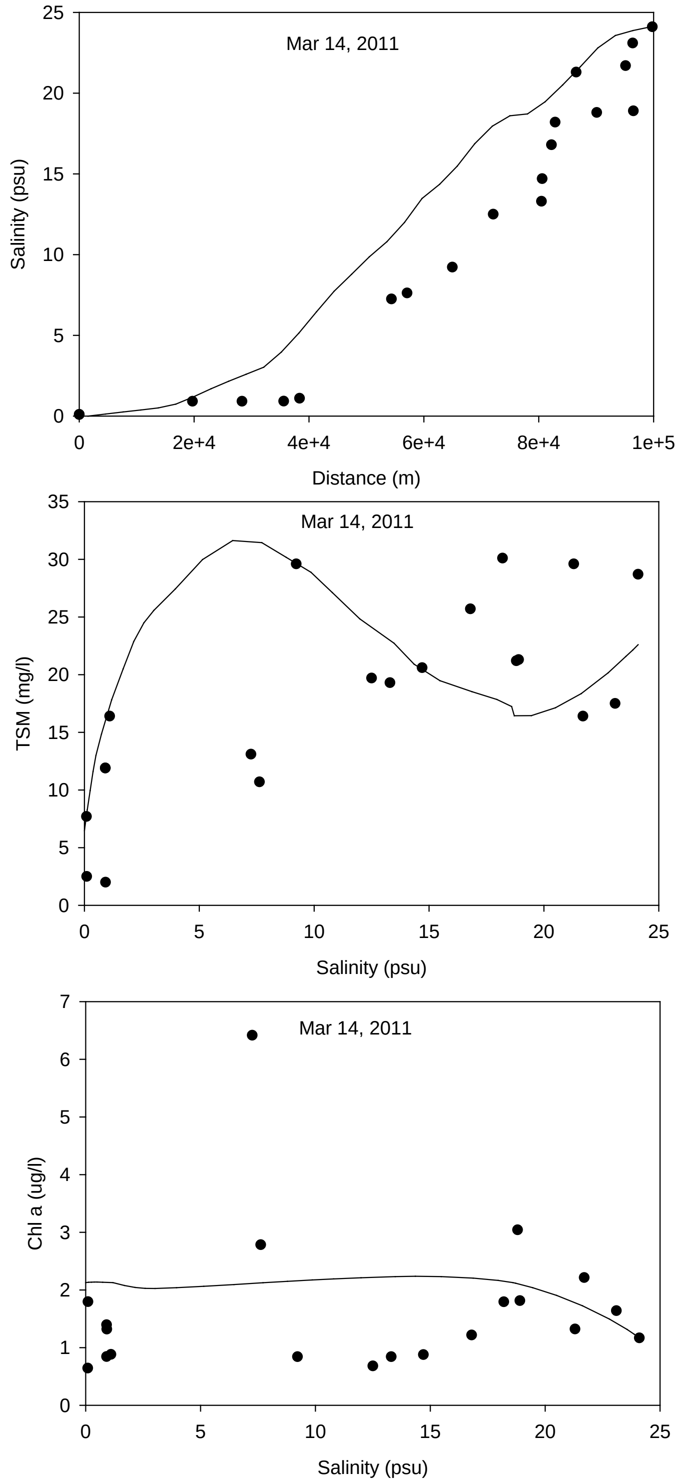

Figure A-5
Model simulated salinity, TSM, and Chlorophyll a compared to observed values for the spring 2011 transect.

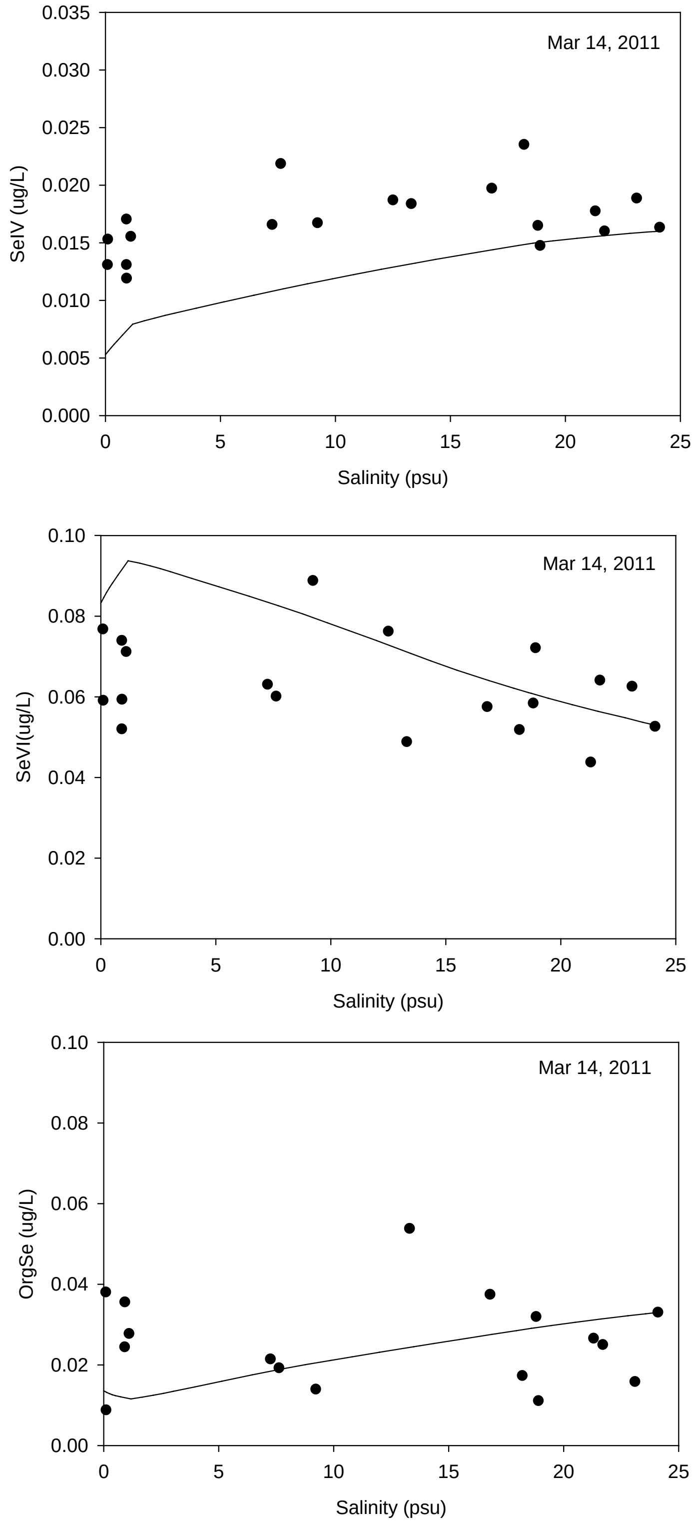

Figure A-6
Model simulated selenite, selenate and organic selenide compared to observed values for the spring 2011 transect.

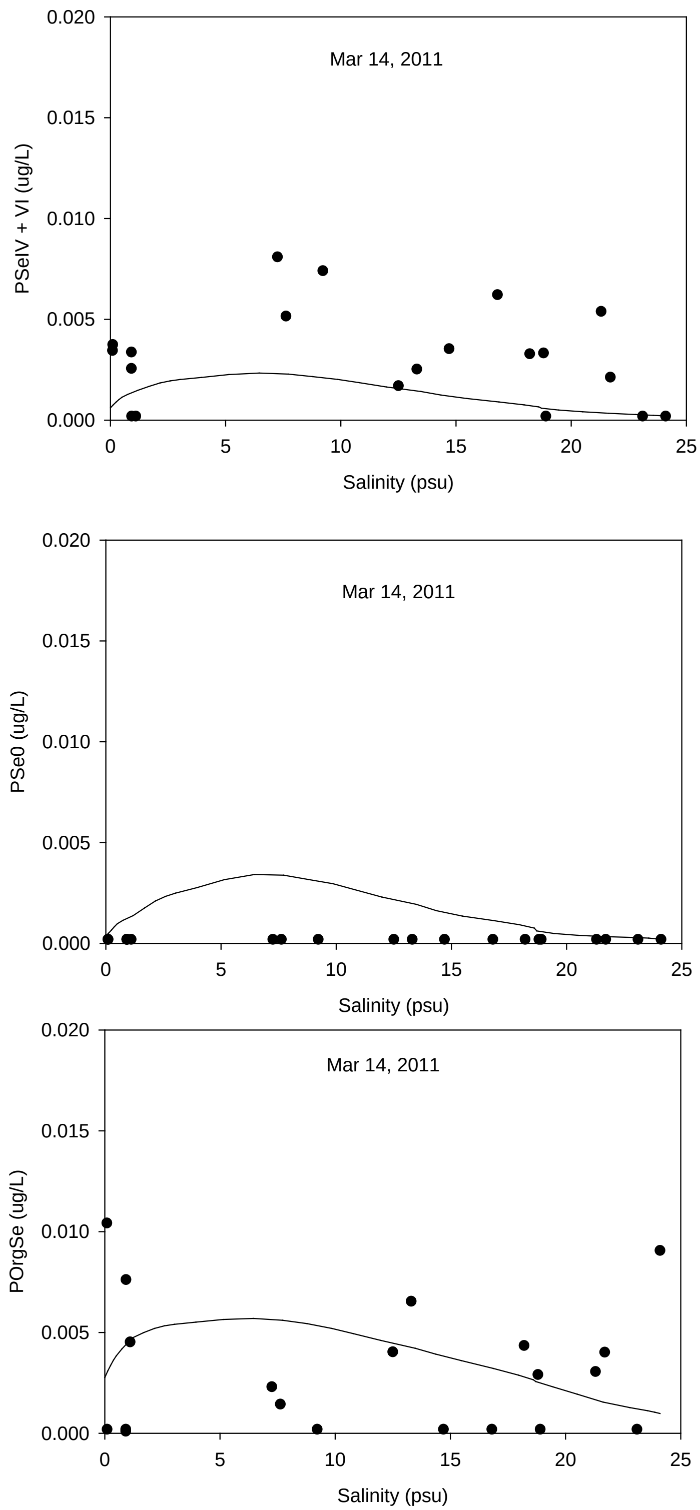

Figure A-7
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values in the spring 2011 transect.

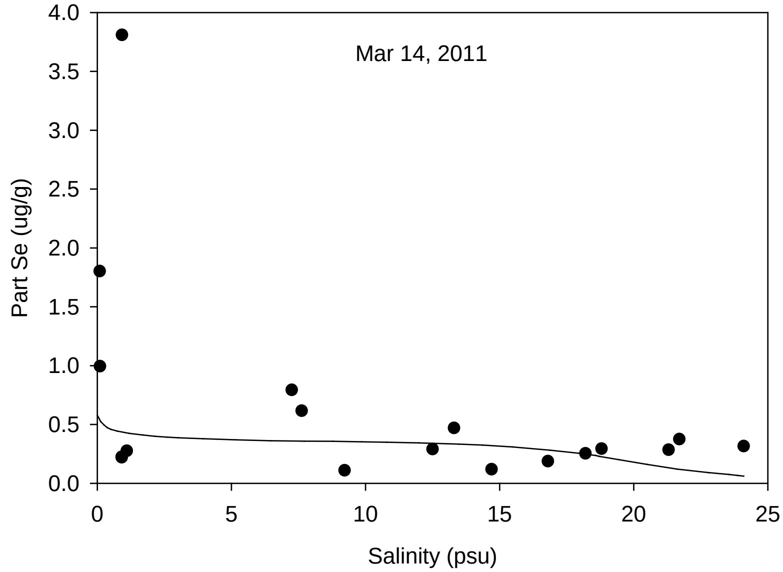

Figure A-8
Model simulated particulate selenium (in µg/g) compared to observed values for the spring 2011 transect.

Fall 2011 Transect

The October 2011 dry season sampling showed good agreement of model-simulated salinity with observed values (NSE =0.999 and GOF = 93.47%) and with observed values for TSM (NSE = 0.969 and GOF =94.85%; Figure A-9). The model is able to capture the location and magnitude of the estuary turbidity maximum exhibited in this profile. Observed phytoplankton concentrations are missing from this sampling event, therefore data from the USGS bay cruise sampling for the nearby dates were used for comparison. The model is generally able to capture the trend in phytoplankton exhibited in the estuary near the fall 2011 sampling event.

The predicted dissolved selenium species generally agreed with the observed values (NSE =0.930-0.948; GOF = 79.2-87%; Figure A-10). Some slight under-predictions were seen for selenite and selenate. This under-prediction could be due to uncertainties in riverine dissolved selenium concentrations and speciation. Particulate selenium species were simulated well by the model (NSE = 0.922 - 9.62; GOF = 79.87 - 98.97%; Figure A-11). Simulated particulate selenium (in µg/g) values mimic the pattern exhibited in the estuary transect, with higher concentrations at the head of the estuary, decreases in particulate selenium up to salinity 2.5 and further increases in particulate selenium towards the Golden Gate (Figure A-12).

The model performance for the 2011 dry season was considered the best among the four transects, as measured by various criteria (Table A-3). The NSE values are greater than 0.85 for all species simulated (including TSM, dissolved and particulate selenium species). The GOF is greater than 79% for all species simulated. Percent bias is less than 20% for all species except POrgSe.

Spring 2012 Transect

For the spring 2012 sampling, simulated salinity showed slight over-predictions (Figure A-13). The model is able to capture the location of the ETM, however, it under-predicted its magnitude. There is good agreement between the simulated and observed phytoplankton. The dissolved selenium species from spring 2012 are also generally predicted well by the model (NSE = 0.90-0.97; GOF = 01.37 – 96.90; Figure A-14). The model is able to predict the relatively conservative behavior of selenate and some slight peaks in the middle of the estuary, the general decreasing trend in organic selenide and the increasing trend in selenite. The selenite calculations showed some under-predictions in peaks in estuary. This under-prediction could be due to uncertainties in riverine dissolved selenium concentrations and speciation. The particulate selenium species are generally predicted well by the model (NSE=0.499 - 0.952; Figure A-15). The particulate elemental selenium concentrations during this high flow sampling event are low (mostly at non-detect levels) and were slightly over-predicted by the model. The model simulated particulate selenium (in µg/g) showed an over-prediction (Figure A-16) due to two factors:1) under-prediction in ETM, and 2) some over-prediction in elemental selenium.

The model performance for the spring 2012 transect measured by NSE is relatively high, with NSE values generally greater than 0.82 for all species except PSe0 (Table A-4). The percent bias (PBIAS) is generally less than 15%, and the goodness of fit (GOF) usually greater than 85% for salinity and dissolved selenium species. Particulate selenium species, due to local variations not captured by the model, generally showed larger percent bias and lower goodness of fit. Overall the fit for particulate selenium (in µg/g) is still relatively good (NSE =0.822 and GOF = 83.12%), and for PSeIV+VI (NSE = 0.952 and GOF = 88.01%).

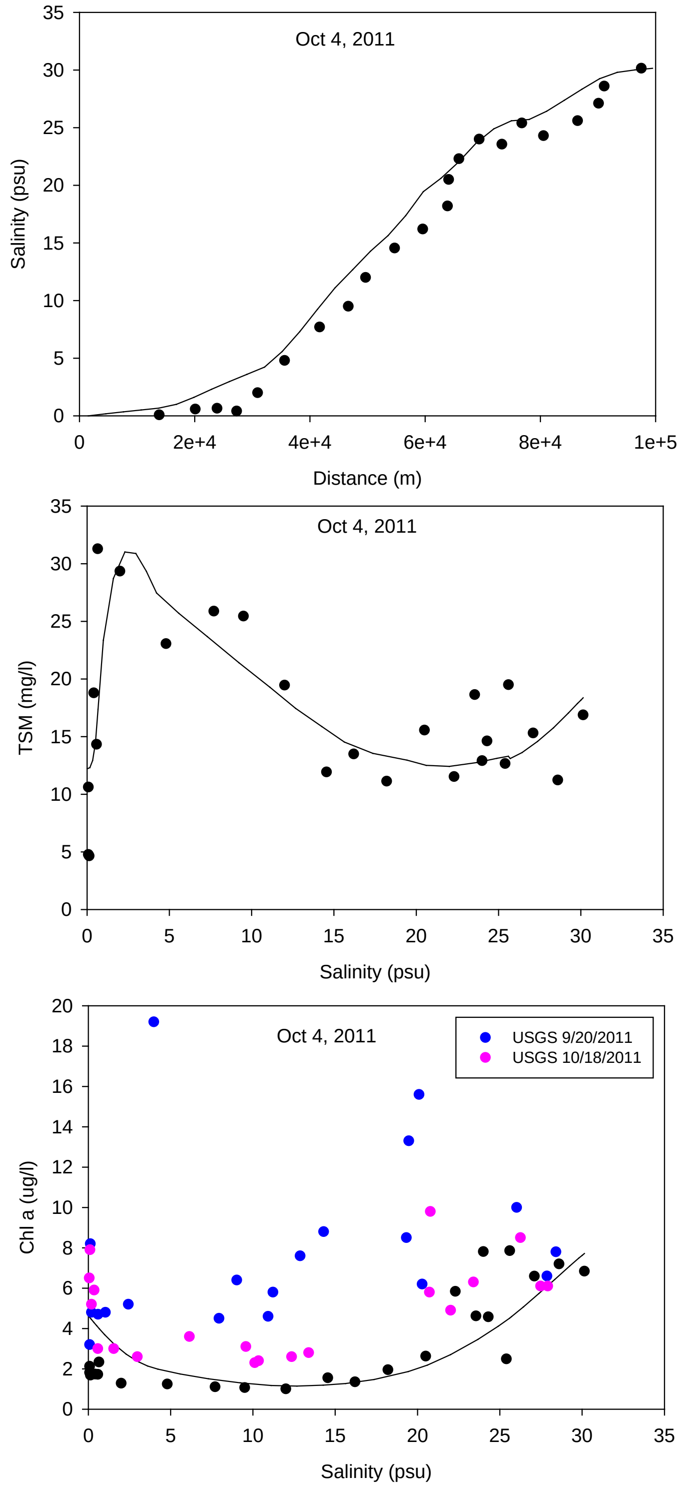

Figure A-9
Model simulated salinity, TSM, and Chlorophyll a compared to observed values for the 2011 dry season transect.

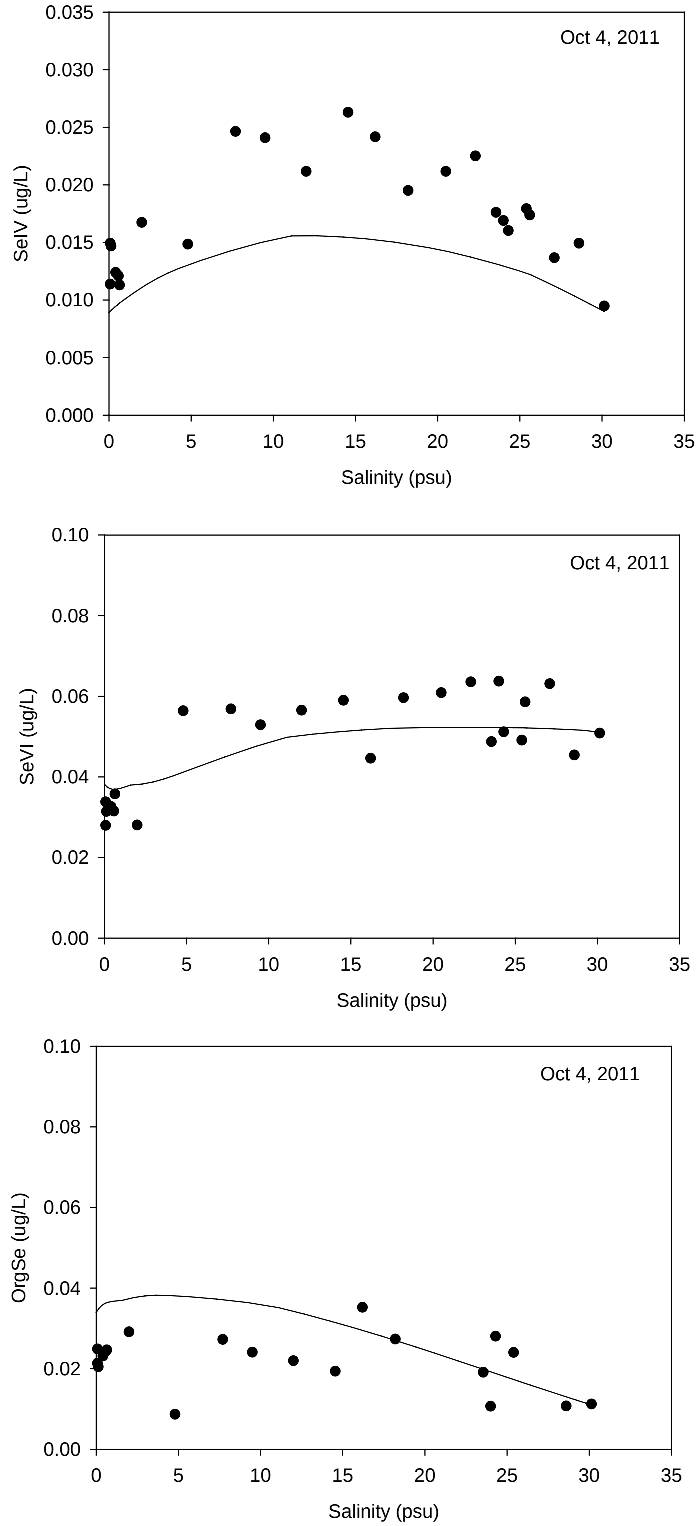

Figure A-10
Model simulated selenite, selenate and organic selenide compared to observed values for the 2011 dry season transect.

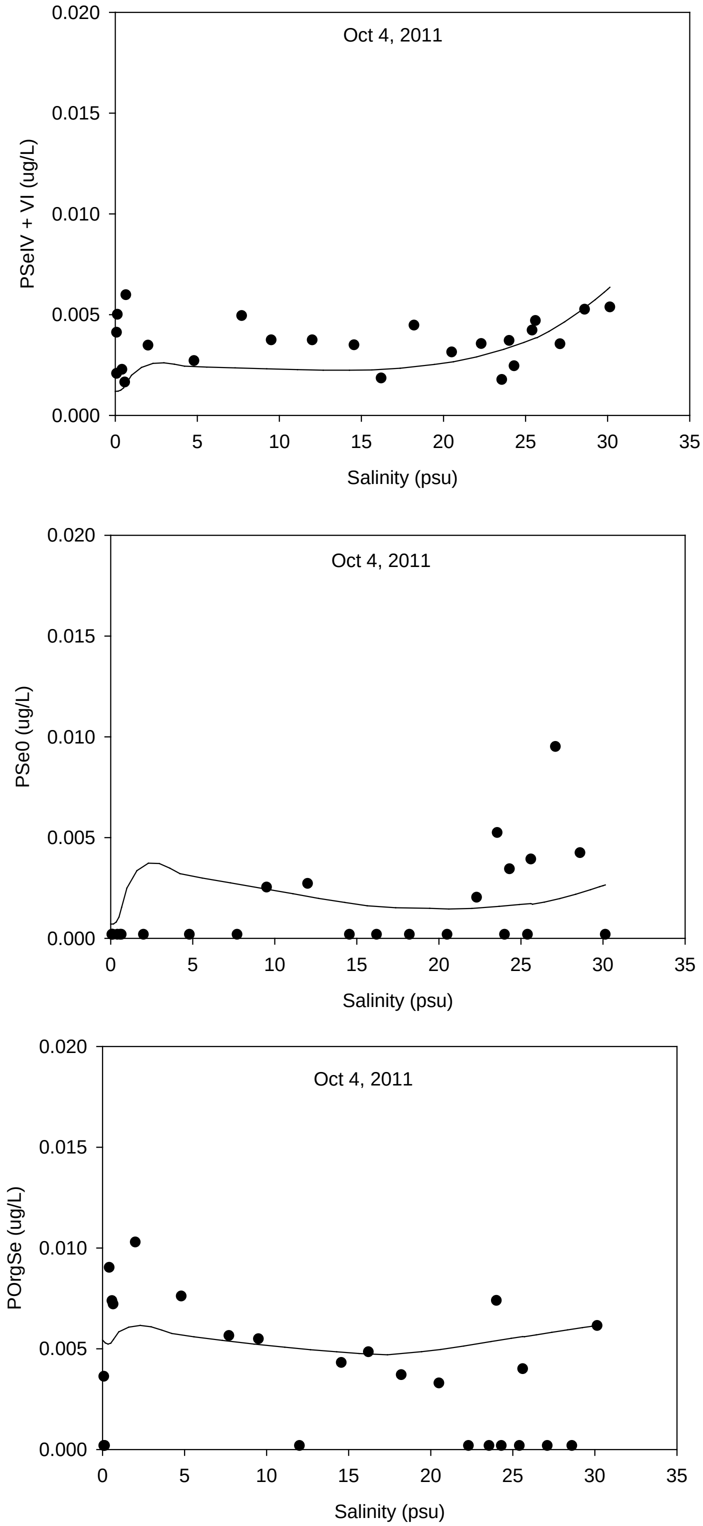

Figure A-11
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values for the 2011 dry season transect.

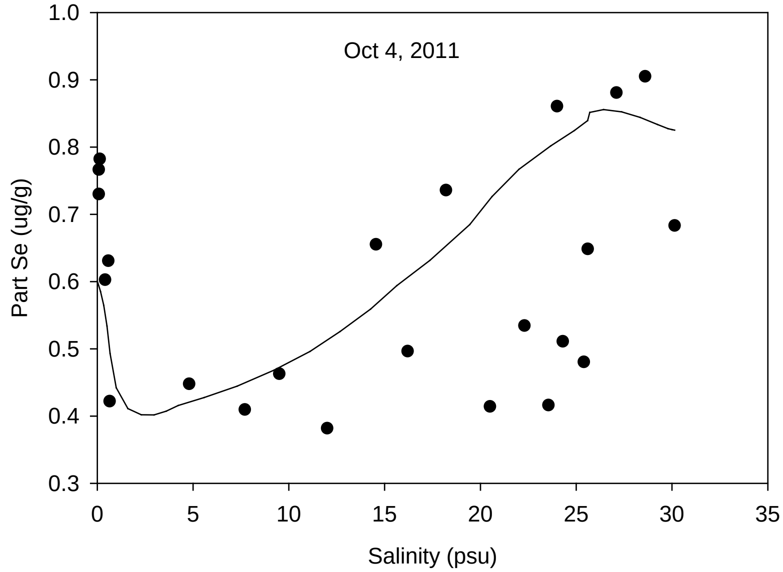

Figure A-12
Model simulated particulate selenium (in μg/g) compared to observed values for the 2011 dry season transect.

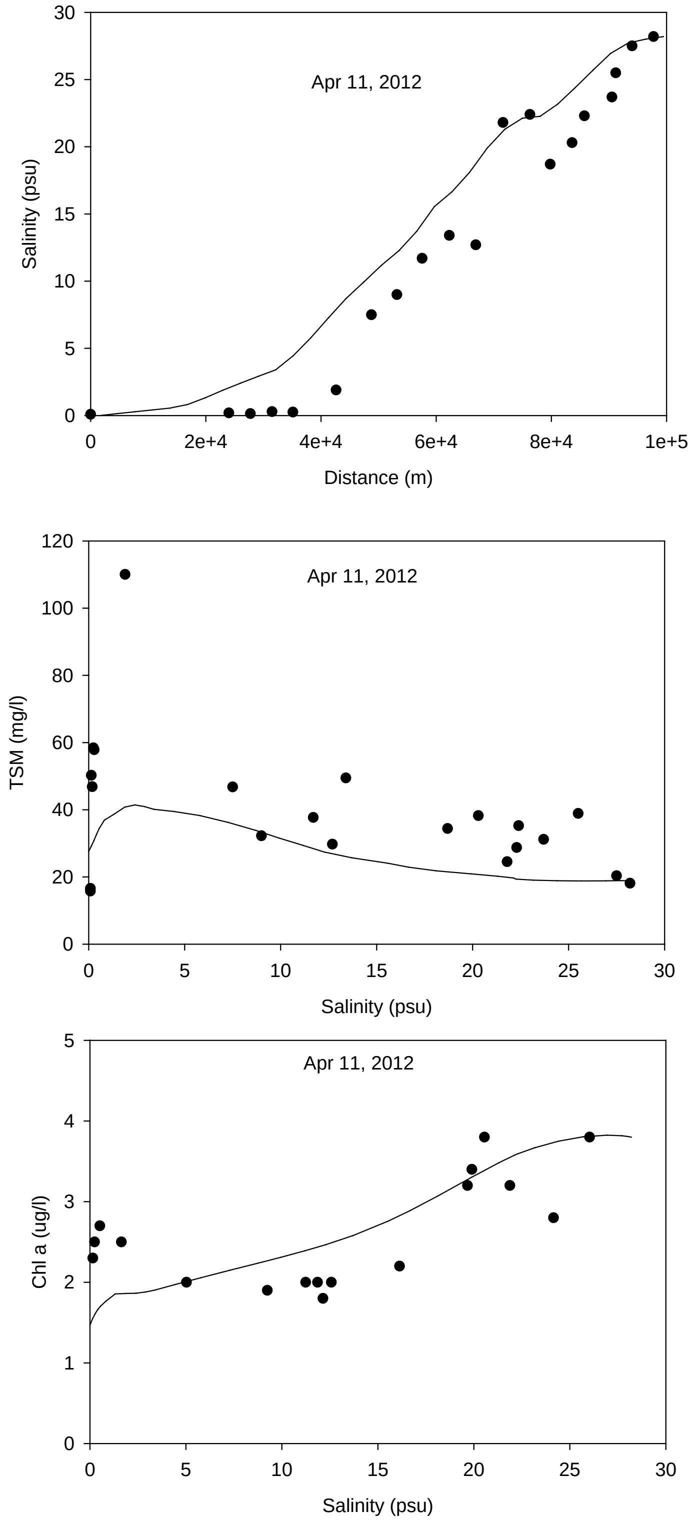

Figure A-13
Model simulated salinity, TSM, and Chlorophyll a compared to observed values for the spring 2012 transect.

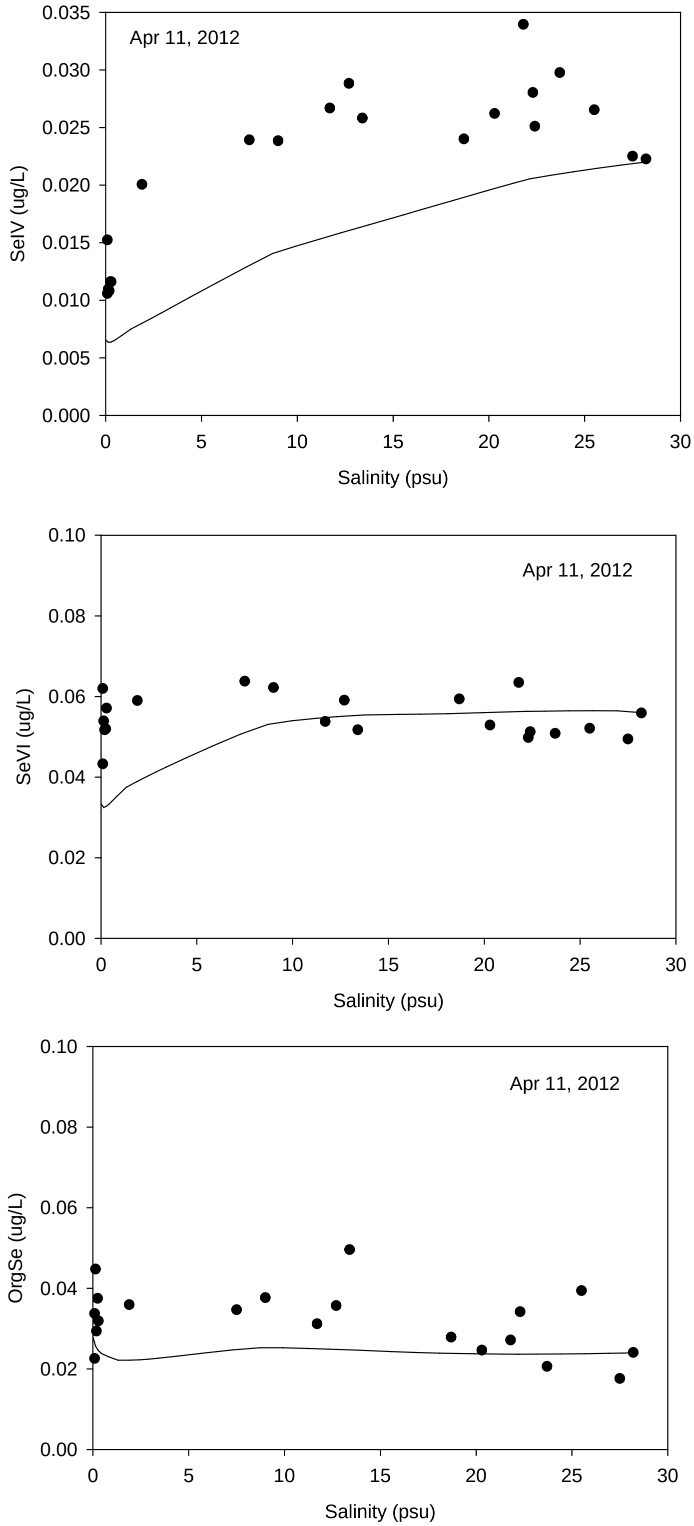

Figure A-14
Model simulated selenite, selenate and organic selenide compared to observed values for the spring 2012 transect.

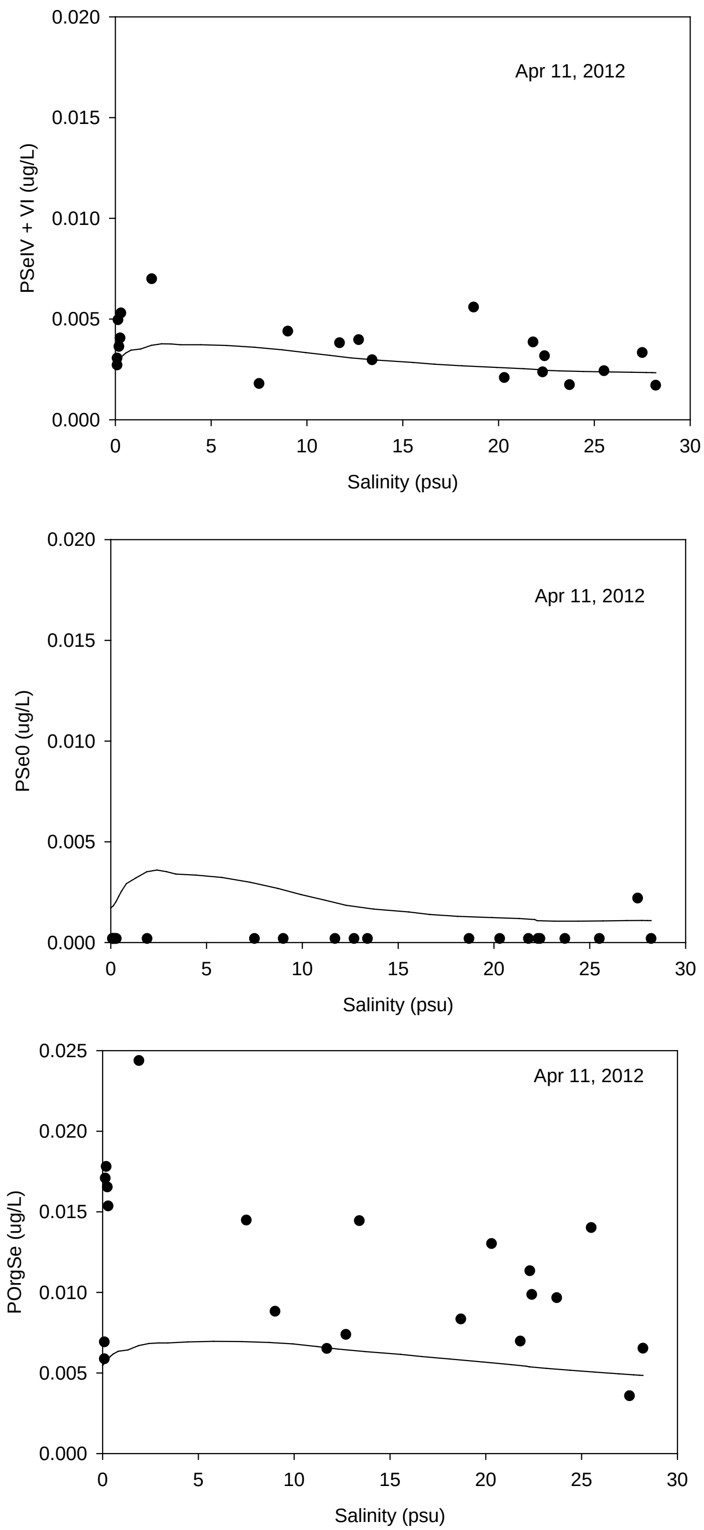

Figure A-15
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values compared to the spring 2012 transect.

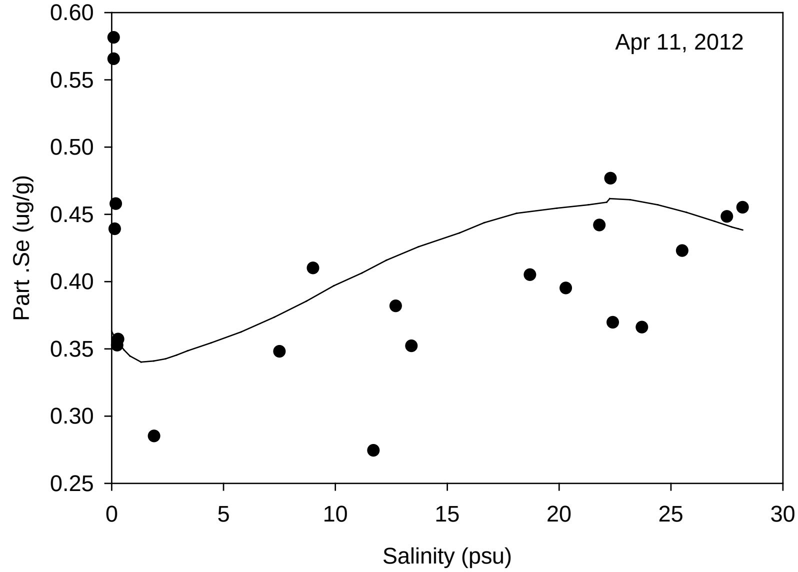

Figure A-16
Model simulated total particulate Se values compared to spring 2012 transect observations.

Table A-1
Statistical Measures for Goodness of Fit for Simulations of the September 2010 Transect

		Field salinity (psu)	Lab salinity (psu)	SeIV (µg/l)	SeVI (µg/l)	Total Dis. Se (µg/l)	Org Se (µg/l)	Chla (µg/l)	TSM (mg/l)	Total Part. Se (µg/l)	PSeIV + VI (µg/l)	PSe0 (µg/l)	POrg Se (µg/l)	Part Se (µg/g)
MSE	optimal 0	6.13	6.03	0.00	0.00	0.00	0.00	0.46	704.00	0.00	0.00	0.00	0.00	0.19
RMSE	optimal 0	2.476	2.455	0.005	0.007	0.020	0.012	0.677	26.533	0.008	0.002	0.011	0.008	0.431
PBIAS	optimal 0	-8.723	-7.998	12.267	14.051	16.003	19.166	-30.186	-26.882	38.536	43.521	-73.570	140.455	98.136
GOF(%)		90.87	92.18	88.42	86.84	85.14	82.44	63.87	68.56	67.26	63.67	-43.10	9.42	30.28
r		0.980	0.977	0.547	0.934	0.613	-0.171	0.513	-0.608	-0.016	-0.143	0.039	-0.090	-0.517

Table A-2
Statistical Measures for Goodness of Fit for Simulations of the March 2011 Transect

		Field salinity (psu)	Lab salinity (psu)	SeIV (µg/l)	SeVI (µg/l)	Total Dis. Se (µg/l)	Org Se (µg/l)	Chla (µg/l)	TSM (mg/l)	Total Part. Se (µg/l)	PSeIV + VI (µg/l)	PSe0 (µg/l)	POrg Se (µg/l)	Part Se (µg/g)
MSE	optimal 0	11.44	15.60	0.005	0.017	0.011	0.014	9.604	10.416	0.004	0.003	0.00	0.003	0.832
RMSE	optimal 0	3.383	3.950	-2.145	-1.352	-0.214	-0.102	-0.709	-0.950	-1.906	-0.792	0.001	-0.405	0.057
PBIAS	optimal 0	21.323	15.248	-22.270	8.702	3.366	9.784	-60.424	10.399	-5.765	-69.800		6.184	-50.936
GOF(%)		80.64	78.35	74.74	91.65	96.69	90.85	3.95	90.10	94.06	-27.01		94.00	27.28
r		0.968	0.923	0.421	0.197	0.095	0.126	-0.044	-0.474	-0.169	0.135		-0.041	0.285

Table A-3
Statistical Measures for Goodness of Fit for Simulations of the October 2011 Transect

		Field salinity (psu)	Lab salinity (psu)	SeIV (µg/l)	SeVI (µg/l)	Total Dis. Se (µg/l)	Org Se (µg/l)	Chla (µg/l)	TSM (mg/l)	Total Part. Se (µg/l)	PSeIV + VI (µg/l)	PSe0 (µg/l)	POrg Se (µg/l)	Part Se (µg/g)
MSE	optimal 0	1.54	1.21	0.00	0.00	0.00	0.00	2.17	26.42	0.00	0.00	0.00	0.00	0.09
RMSE	optimal 0	1.242	1.098	0.007	0.011	0.021	0.014	1.471	5.140	0.002	0.002	0.003	0.003	0.303
PBIAS	optimal 0	6.688	2.881	-35.301	-9.557	-5.389	36.265	-7.59	2.827	10.447	-21.54	32.797	31.938	2.679
GOF(%)		93.47	95.05	66.15	95.74	98.47	60.67	96.34	94.85	86.97	86.40	70.71	71.86	85.79
r		0.997	0.994	0.862	0.798	0.638	0.496	0.795	0.663	0.622	0.343	-0.176	0.256	0.376

Table A-4
Statistical Measures for Goodness of Fit for Simulations of the April 2012 Transect

		Field salinity (psu)	Lab salinity (psu)	SeIV (µg/l)	SeVI (µg/l)	Total Dis. Se (µg/l)	Org Se (µg/l)	Chla (µg/l)	TSM (mg/l)	Total Part. Se (µg/l)	PSeIV + VI (µg/l)	PSe0 (µg/l)	POrg Se (µg/l)	Part Se (µg/g)
MSE	optimal 0	7.09	6.75	0.0000	0.0001	0.0005	0.0001	1.10	457.10	4.1E-05	1.9E-06	3.8E-06	0.0001	0.00
RMSE	optimal 0	2.664	2.599	0.007	0.008	0.021	0.012	1.048	21.380	0.006	0.001	0.002	0.008	0.068
PBIAS	optimal 0	14.229	14.118	-26.041	-5.155	-15.955	-26.712	14.986	-35.712	-31.268	-18.924	518.659	-50.227	6.146
GOF(%)		86.69	86.78	69.72	94.71	82.60	74.24	86.02	55.46	62.28	78.98	-108.52	28.81	94.03
r		0.986	0.971	0.839	0.083	0.363	-0.013	0.399	0.66	0.76	0.56	-0.19	0.64	0.19

A.2 Validation for the 1999 Transects

The model with relevant inputs of refinery, tributary and local dischargers, boundary conditions, selenium uptake rates, updated salinity formulation and TSM calibration, was validated for the 1999 sampling transects.

Spring 1999 Transect

For the April 1999 transect, model-simulated physical parameters agreed well with the model (GOF= 68.6 – 84.9%; Figure A-17). The model is able to capture the location and magnitude of the ETM for the April 1999 transect, which is considered as an improvement over the previous modeling result. Dissolved selenium species showed very similar patterns to the previous results (GOF = 67.6-92.6%; Figure A-18; Tetra Tech, 2010). The organic selenide seems slightly under-predicted. There are also local variations in organic selenide that are not captured by the model. This could be due to the speciation of refineries (values sampled in October 1999) and tributaries (values sampled in March 2012) assumed in the model.

Particulate selenium species showed behavior similar to previous results, but with generally better agreement with the spatial pattern (i.e., location and magnitude of estuary peaks; Figure A-19; GOF = 48.08-77.66%). The particulate organic selenide showed some over-prediction. This indicates dissolution (mineralization) of particulate organic selenide to dissolved organic selenide may be possibly underestimated. Model simulated particulate selenium (in µg/g) showed very good agreement with observed values for April 1999 transect, capturing the general spatial pattern observed in particulate selenium (Figure A-20). Model performance evaluation for April 1999 is shown in Table A-5.

Fall 1999 Transect

The November 1999 simulation showed results similar to previous modeling, with good agreement for salinity, and some over-prediction in TSM (GOF = 75.88 – 95.5%; Figure A-21). The agreement for simulated and observed chlorophyll a concentrations is high (GOF = 86.62%). With the updated inputs of selenium from refineries, tributaries and local dischargers and better speciation data, the model is able to better capture the estuary peaks in dissolved selenium species, particularly for selenate and organic selenide (GOF = 75.17 – 94.5%; Figure A-22). The model seems to over-predict selenite in the middle of the estuary.

The model simulated particulate selenium species seem to agree better with observed values, compared to previous simulation (GOF = 49.67% - 98.98%; Tetra Tech, 2010), particularly for particulate elemental selenium (Figure A-23). Simulated particulate selenium (in µg/g) showed similar results to previous modeling (GOF = 91.13%; Figure A-24), with some under-prediction in head of estuary due to over-prediction in TSM. This suggests that a TSM calibration that works for one condition (e.g., October 2011 may not work as well for other conditions). The model performance evaluation for November 1999 is shown in Table A-6.

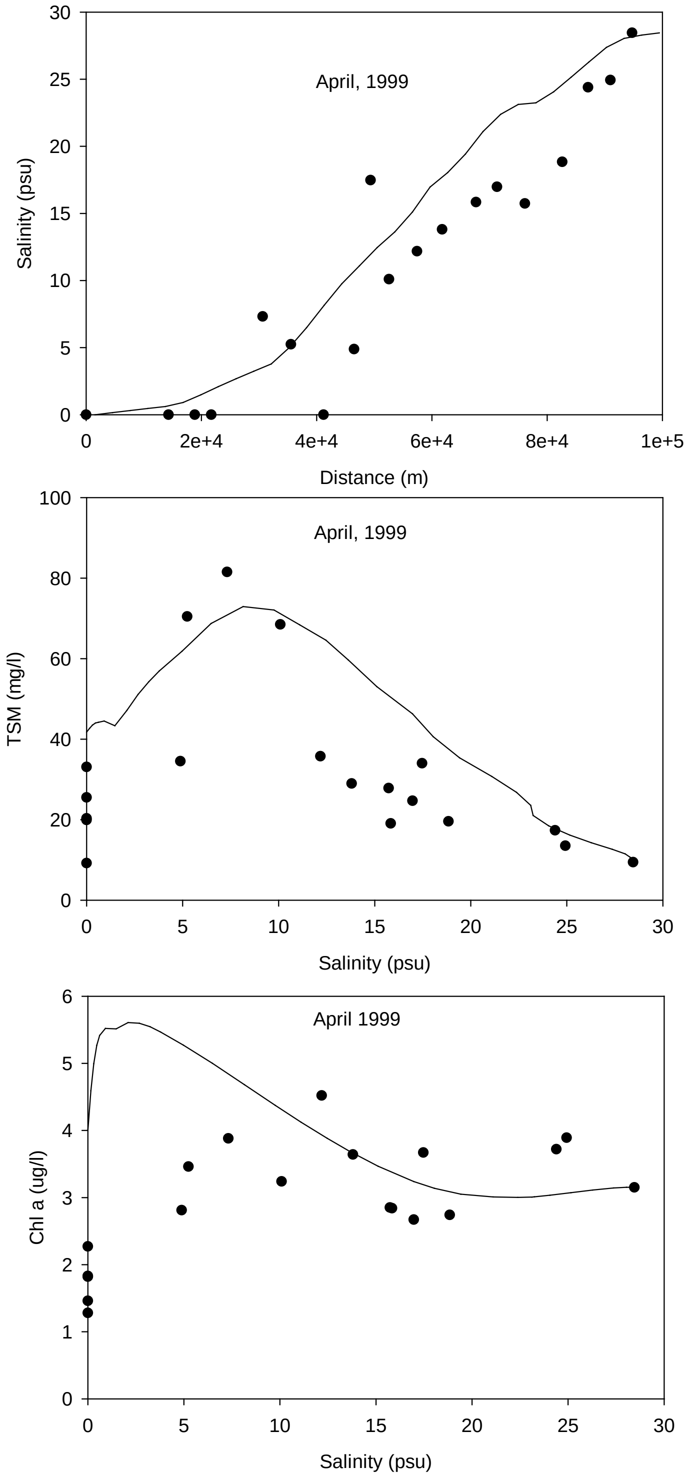

Figure A-17
Model simulated salinity, TSM, and Chlorophyll a compared to observed values for the April 1999 transect.

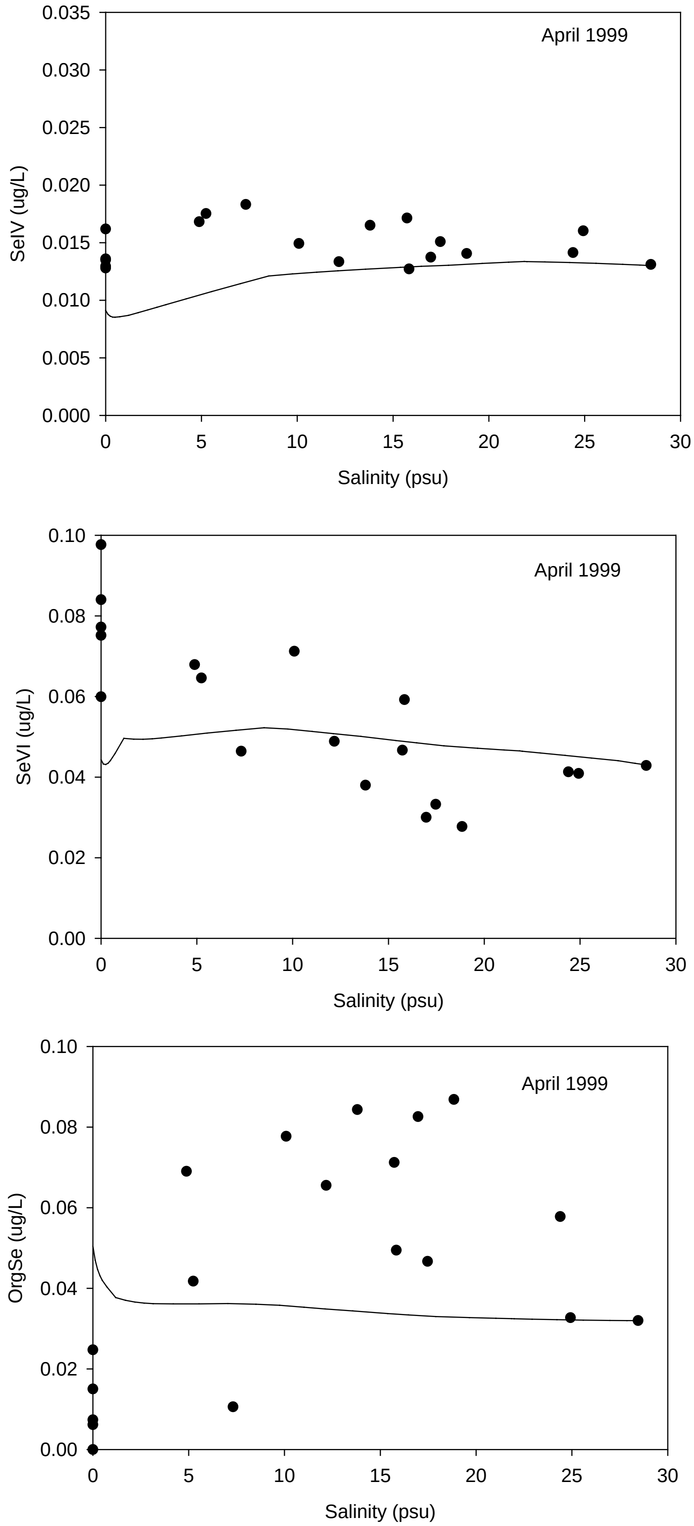

Figure A-18
Model simulated selenite, selenate and organic selenide compared to observed values for the April 1999 transect.

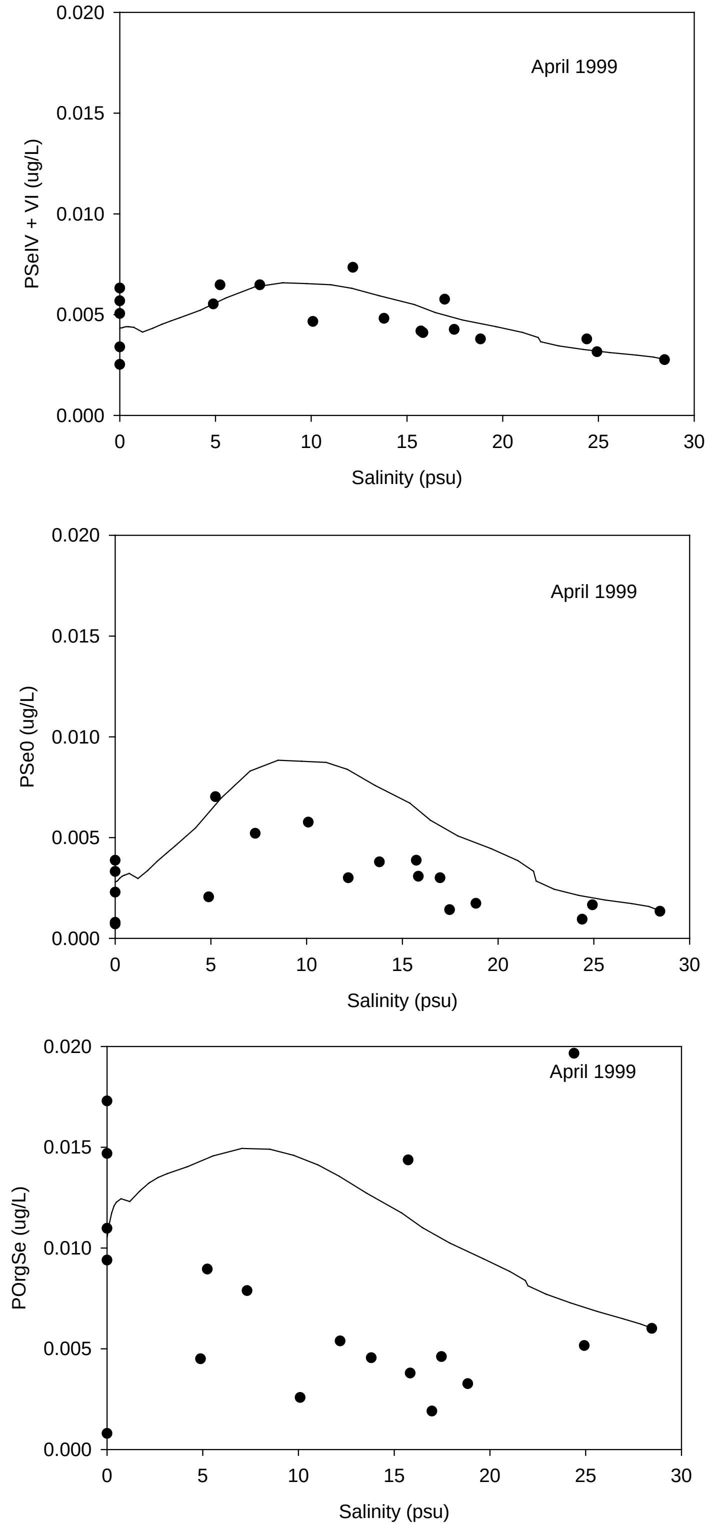

Figure A-19
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values compared to the April 1999 transect.

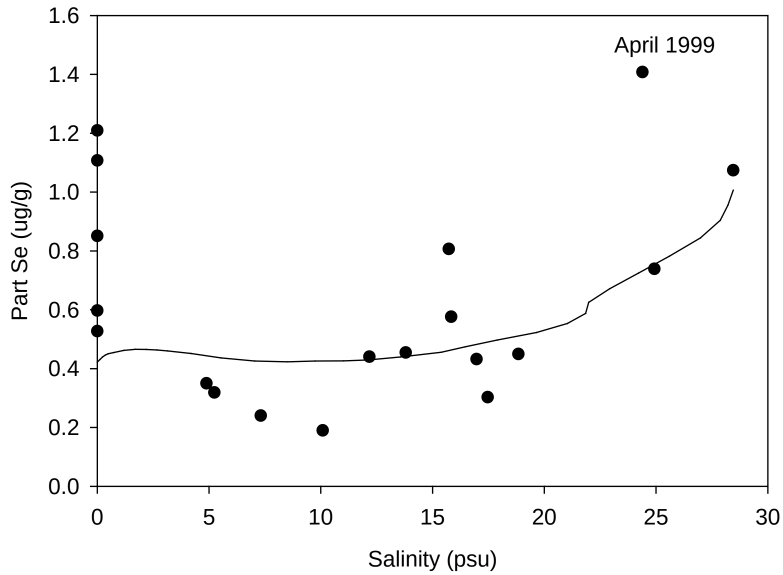

Figure A-20
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values compared to the April 1999 transect.

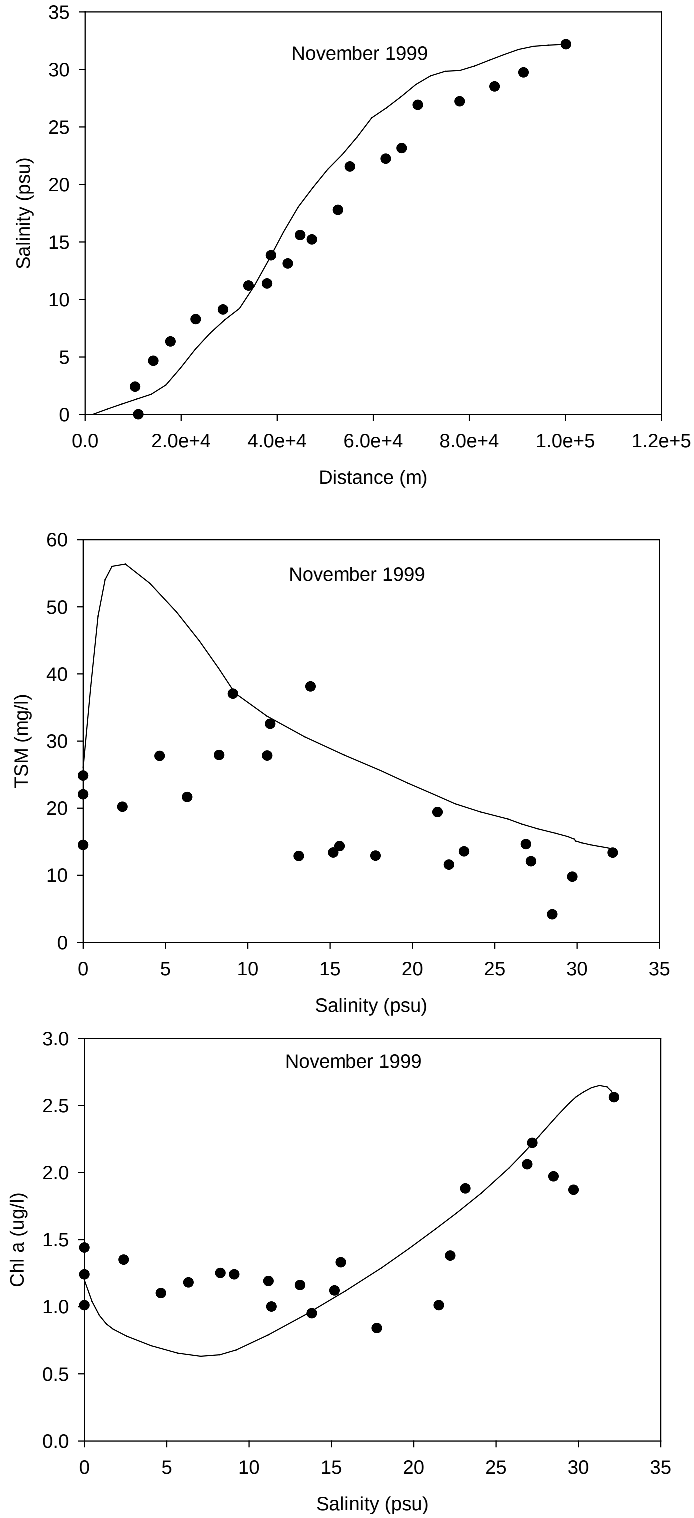

Figure A-21
Model simulated salinity, TSM, and Chlorophyll a compared to observed values for the November 1999 transect.

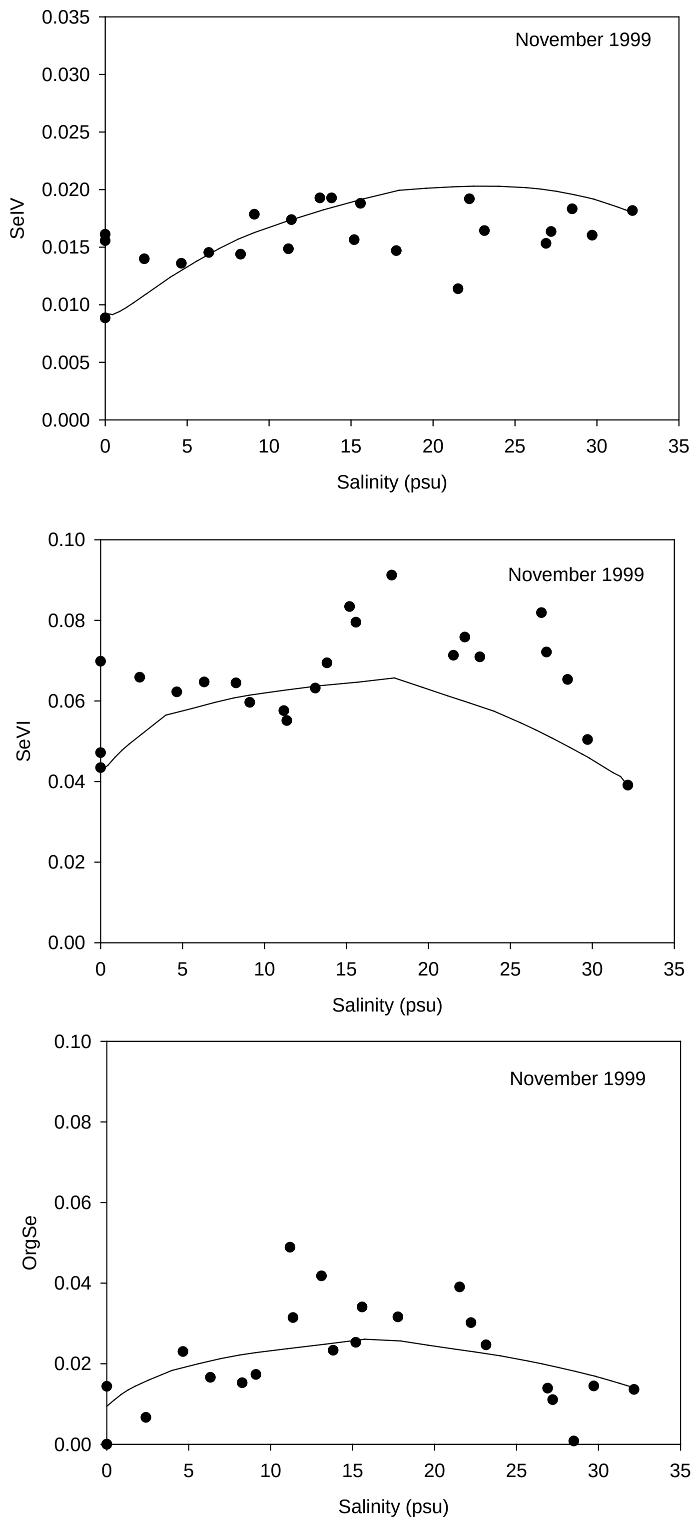

Figure A-22
Model simulated selenite, selenate and organic selenide compared to observed values for the November 1999 transect.

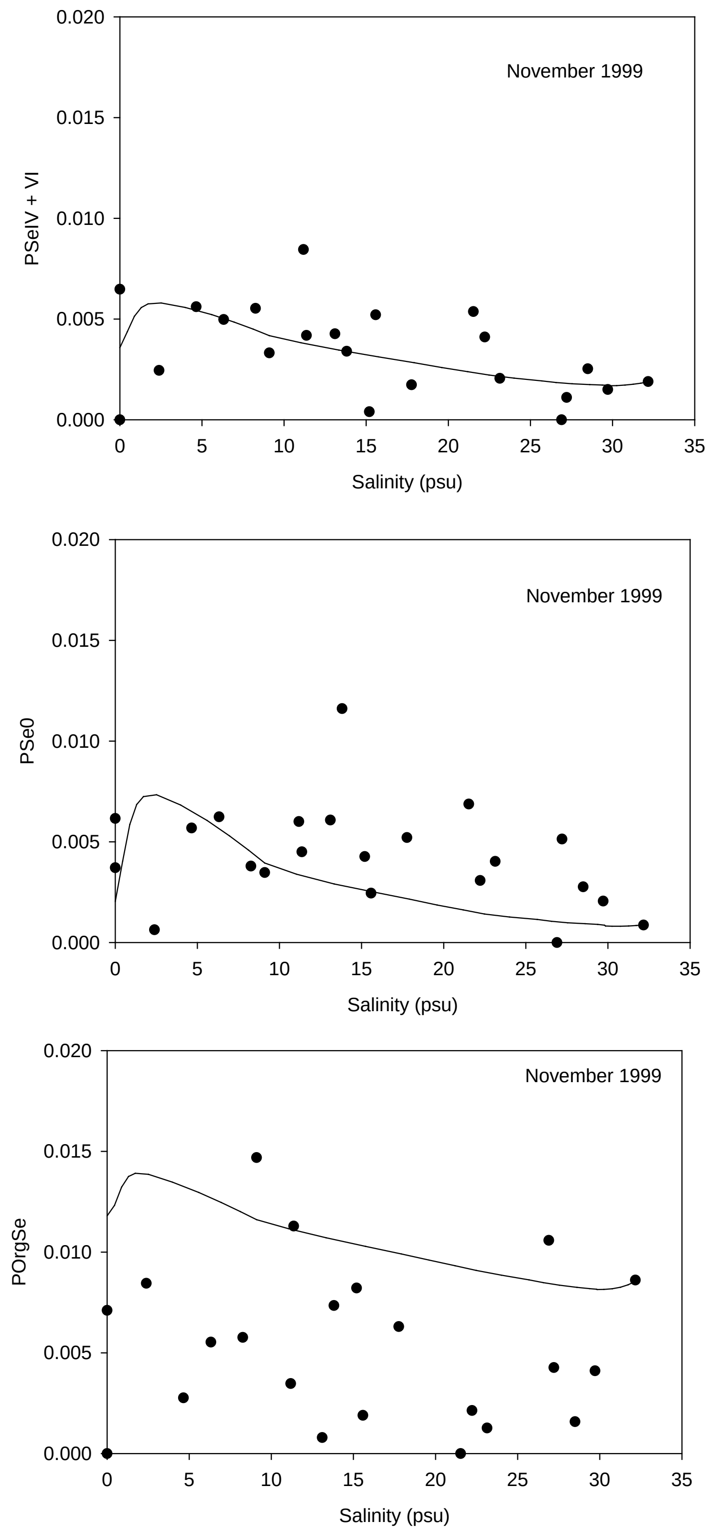

Figure A-23
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values compared to the November 1999 transect.

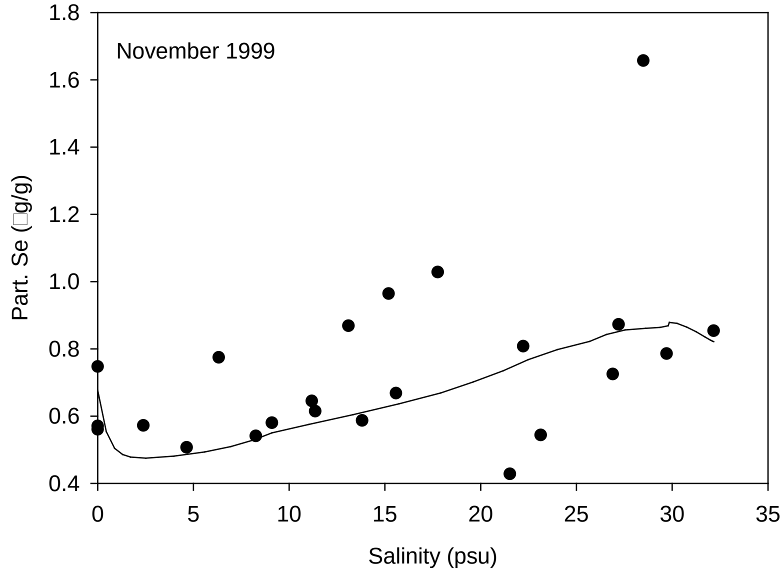

Figure A-24
Model simulated particulate selenite and selenate, particulate elemental selenium, and particulate organic selenium compared to observed values compared to the November 1999 transect.

A.3 Predicted Clam Selenium Concentrations

Model-simulated selenium concentrations in clams (*P. amurensis*) at Carquinez Strait were compared to observed data from the USGS at the Carquinez Strait (USGS station 8.1; Stewart et al. 2013). Results suggested that the model is able to capture the inter-annual and seasonal variations in selenium concentrations in clams. The year 2012 is considered a dry year, which results in high predicted selenium concentrations in clams.

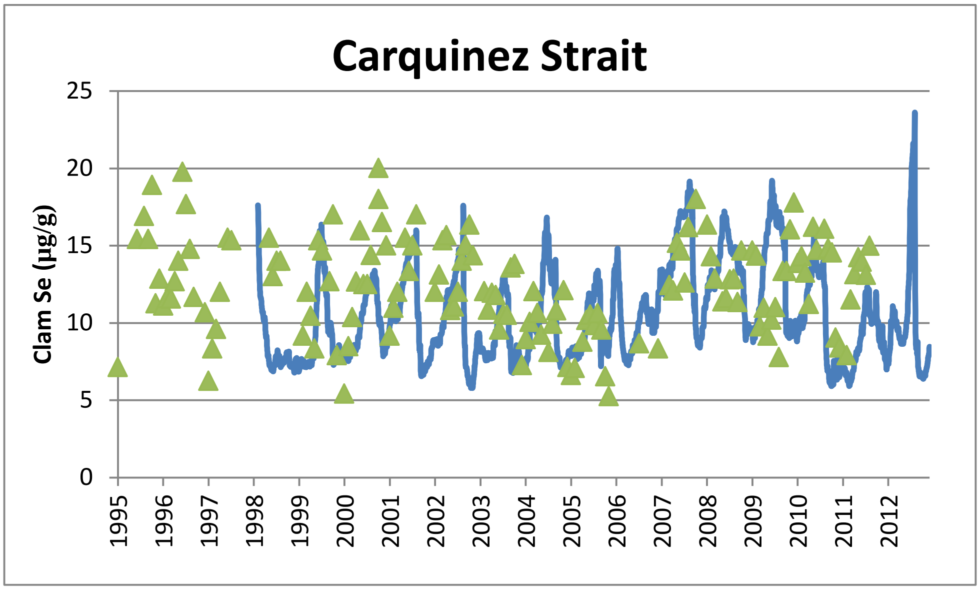

Figure A-25
Model simulated selenium concentrations in clams compared to observed data at Carquinez (Stewart et al. 2013). Blue lines: model predictions; green symbols: USGS data.

Table A-5
Statistical Measures for Goodness of Fit for Simulations of April 1999 Transect

		Field salinity	Lab salinity	SeIV (µg/l)	SeVI (µg/l)	Total Dis. Se (µg/l)	Org Se (µg/l)	Chla (µg/l)	TSM (mg/l)	Total Part. Se (µg/l)	SeIV + VI (µg/l)	Se0 (µg/l)	Org Se (µg/l)	Part Se (µg/g)
MSE	optimal 0	14.94	281.87	0.0000	0.0004	0.0010	0.0010	3.53	269.73	6.5716E-05	1.3351E-06	1.0554E-05	0.0000	0.11
RMSE	optimal 0	3.866	16.789	0.004	0.021	0.032	0.032	1.880	16.424	0.008	0.001	0.003	0.007	0.332
PBIAS	optimal 0	16.288		-20.730	-12.870	-19.236	-26.188	36.718	17.255	41.646	1.784	61.267	39.801	-1.181
GOF(%)		84.90		76.72	86.21	78.60	69.52	68.60	84.06	65.01	98.23	51.75	66.34	98.81
r		0.934		0.025	0.101	0.362	-0.604	-0.42	0.65	0.54	0.58	0.20	-0.09	0.34

Table A-6
Statistical Measures for Goodness of Fit for Simulations of November 1999 Transect

		Field Salinity	Lab Salinity	SeIV (µg/l)	SeVI (µg/l)	Total Dis. Se (µg/l)	Org Se (µg/l)	Chla (µg/l)	TSM (mg/l)	Total Part. Se (µg/l)	SeIV + VI (µg/l)	Se0 (µg/l)	Org Se (µg/l)	Part Se (µg/g)
MSE	optimal 0	6.16	6.16	0.000	0.000	0.000	0.000	0.22	87.78	0.00	0.00	0.00	0.00	0.06
RMSE	optimal 0	2.482	2.482	0.004	0.017	0.018	0.010	0.469	9.369	0.006	0.002	0.003	0.007	0.249
PBIAS	optimal 0	4.561	4.561	3.807	-19.302	-14.003	-10.942	14.301	27.201	29.615	-6.425	-28.287	102.489	-6.267
GOF(%)		95.54	95.54	96.26	78.51	84.90	88.40	86.62	75.88	73.99	93.36	66.60	27.98	93.53
r		0.984	0.984	0.377	0.410	0.845	0.771	0.798	0.639	0.554	0.600	0.240	0.135	0.386