Technical Memorandum—Evaluation of an Alternative Se Regulatory Criterion Value

January 3, 2013

Prepared by Tetra Tech

Introduction

EPA Region 9 has announced that it will draft site-specific numeric selenium (Se) criteria to protect aquatic species in the Bay Delta Estuary (EPA, 2011). EPA also made the recommendation that the San Francisco Bay RWQCB use the site-specific criteria under development by EPA in the North San Francisco Bay TMDL (EPA, 2012). EPA staff have stated that the technical basis for the development of the selenium criteria will be the ecosystem-based model developed by the USGS, which is described in the 2010 USGS Administrative Report (Presser and Luoma, 2010a).

The goal of this technical memorandum is twofold: (1) to provide a summary of the technical approach and likely outcome of EPA's ongoing Se criterion development process, including an evaluation of the ability of the refinery discharges to meet the anticipated "allowable"[1] water-column Se concentrations; and (2) to evaluate the feasibility of developing an alternative Se criterion value that is protective of the environment and technically defensible.

This technical memorandum brings together the results from several presentations and discussions surrounding EPA's effort to develop and promulgate a new Se water-column criterion value that have taken place over the past two years. We believe that bringing this information together into one document will provide a more detailed understanding of the ongoing regulatory efforts and the consequences of these efforts on future refinery permit conditions.

There are five parts to this summary and evaluation of the existing information:

- Part 1: Summary of our understanding of the technical approach that EPA is relying on to develop an allowable water-column Se concentration as the proposed criterion value. In addition, the Se concentrations that EPA is likely to select are presented and compared to the Se concentrations measured in the recently completed Selenium Characterization Study Report (Tetra Tech, 2012).
- Part 2: Report on Tetra Tech's efforts to develop an alternative dissolved Se concentration criterion value. Based on earlier EPA reports (EPA, 2011) and discussions with EPA staff, it is clear that their intent is to develop a dissolved Se concentration

[1] The term allowable does not have a statutory or regulatory definition, but is the terminology employed in Presser and Luoma (2010a). The allowable terminology is carried forward in this document to describe the potential water-column regulatory criterion concentrations for Se calculated with the USGS ecosystem-based model.

criterion value. An alternative approach which takes advantage of the information gained in the Se Characterization Study (Tetra Tech, 2012) and Se modeling results (Tetra Tech, 2010) is presented and evaluated.

- Part 3: Report on the efforts to develop an alternative particulate Se concentration criterion value. The refineries discharge primarily (~ 98%) dissolved Se, but the particulate Se concentration is a critical factor in the development of the EPA allowable dissolved Se concentration. Using new data on the characterization of the Se concentrations in refinery effluents and at Bay-Delta sampling stations, the feasibility of developing an alternative Se particulate criterion value is evaluated.
- Part 4: Consideration of alternative feeding preferences on the calculation of a fish target tissue concentration. One of the assumptions in the calculation of the allowable water-column Se concentration presented in the 2010 USGS Administrative Report is that the diet of the target fish consists exclusively of the invasive clam *Corbula amurensis*. The effect of broader-based diets on the resulting allowable water-column Se concentration is explored.
- Part 5: Summary of the findings from the evaluation of alternative regulatory approaches. The results of the analyses are presented in the terms of the ability of the refineries and other sources to meet permit limits that might consider these alternatives.

Part 1: Summary of EPA's Approach to the Development of a Se Criterion Value

The USGS ecosystem-scale methodology for Se criterion development is presented in Figure 1. The allowable dissolved Se concentration (Se_{DISS}) in the water column is back-calculated from the selected target fish Se concentration (Se_{FISH}) in a series of steps, using specified values for trophic transfer factors (TTFs) and a partition coefficient (K_d) and derived values for the allowable prey concentrations and a water-column particulate Se concentration.

- *Step 1. Specification of the Se Target Concentration and Calculation of the Allowable Prey concentration*. The numeric target is expressed as a tissue-based Se concentration, Se_{FISH}, and Equation 1 (Eq. 1) in Figure 1 is used to express the relationship between Se_{FISH}, the Se concentration in the fish prey (Se_{PREY}), and a trophic transfer factor (TTF_{FISH}). Since values for Se_{FISH} and TTF_{FISH} are specified, Se_{PREY} is calculated using Equation 2.
- *Step 2. Calculation of the Allowable Particulate Se Concentration*. The relationship between the allowable prey concentration and the allowable particulate concentration (Se_{PART}) is shown in Eq 3. With the values for Se_{PREY} and TTF_{PREY} specified, Se_{PART} is calculated using Equation 4.
- *Step 3. Calculation of the Allowable Dissolved Se Concentration*. The calculation of the allowable dissolved Se concentration (Se_{DISS}) relies on the specification of a value for the partition coefficient, K_d, which is the ratio of the concentration in the particulate phase to the concentration in the dissolved phase (Equation 5). With the value of Se_{PART} now specified (Eq 4) and the value of K_d specified based on measured values in the estuary, the allowable dissolved Se concentration that is required to achieve a selected fish-target concentration is calculated using Equation 6.

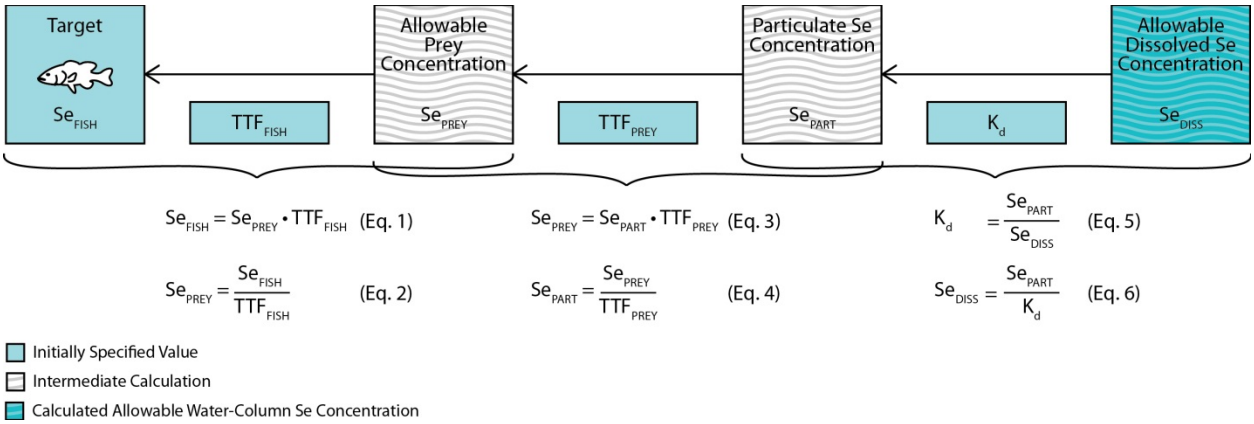

Figure 1. Steps in the USGS approach for the translation of a tissue Se concentration in fish (target) to an allowable water-column Se concentrations for protection of fish and aquatic-dependent wildlife.

One of the primary concerns with the EPA Region 9/USGS approach is the reliance on the partition coefficient (K_d) to derive the allowable dissolved concentration. The relationship between the particulate and dissolved forms of Se in North San Francisco Bay (NSFB) is complex and dependent upon selenium speciation, biological uptake, mineralization, and adsorption/desorption rates. Because of this complexity, the measured values of K_d in NSFB exhibit a great deal of spatial and temporal variability. As shown below, reliance on a fixed value of K_d in the determination of the allowable dissolved concentration results in allowable dissolved concentrations that are less than measured ambient water column concentrations and less than the dissolved Se concentrations measured at the boundary conditions (Sacramento River and Pacific Ocean).

The calculated allowable dissolved Se concentrations (Allowable Se_{DISS}), based on the EPA Region 9/USGS approach, are presented in Table 1. Separate calculations of Allowable Se_{DISS} are presented for measurements made at 24 stations along a transect extending from the Golden Gate Bridge to the Sacramento River, and two sets of comparisons are made using these calculations. In the first set of comparisons, the calculated allowable Se_{DISS} is compared with the Se_{DISS} measured at Freeport on the Sacramento River. The Freeport sampling location was selected to represent boundary conditions and one of the two primary input sources of dissolved Se to NSFB. The Freeport station also represents the natural background concentrations in the region.

Those locations (11 of 24) where the allowable Se_{DISS} is less than the measured concentrations at the Freeport boundary location are highlighted. Although not shown in Table 1, the average dissolved Se concentration at ocean-water stations outside the Golden Gate Bridge (the other primary input source) was approximately equal to the measured value at Freeport (0.063 µg/l vs. 0.064 µg/l).

In the second set of comparisons, the calculated allowable Se dissolved concentration was compared to the measured dissolved Se concentration at the 24 sampling locations. At five of the sampling locations the allowable Se concentration was greater than the ambient measured concentration (highlighted in Table 1). This means that the allowable dissolved Se concentration could not be met at 19 of the 24 sampling stations.

Table 1
Calculated Allowable Dissolved Se Concentrations (Se_{DISS}) using 2011 Dry Season Sampling Data from the Selenium Characterization Study (Tetra Tech, 2012a).
The fixed parameter values used in these calculations were: Target Se_{FISH} = 8.1 ug/g; TTF_{FISH} = 1.1; TTF_{PREY} = 17.1.

Station #	Total $Se_{PART.}$ (µg/g)	Total $Se_{DISS.}$ (µg/L)	Kd (l/g)	Allowable Se $_{DISS.}$ (µg L^{-1})	(Allowable - Measured) Se $_{DISS.}$ (µg L^{-1})	Freeport Se $_{DISS.}$ (µg L^{-1})
T-1	0.68	0.072	9.46	0.046[1]	-0.026	0.064
T-2	0.91	0.071	12.79	0.034	-0.037	0.064
T-3	0.88	0.077	11.45	0.038	-0.039	0.064
T-4	0.65	0.077	8.46	0.051	-0.026	0.064
T-5	0.51	0.095	5.40	0.080	-0.015	0.064
T-6, SPB[2]	0.48	0.091	5.29	0.081	-0.010	0.064
T-7, SPB	0.42	0.085	4.92	0.087	0.002	0.064
T-8, SPB	0.86	0.091	9.45	0.046	-0.045	0.064
T-9, SPB	0.54	0.082	6.56	0.066	-0.016	0.064
T-10, SPB	0.42	0.09	4.64	0.093	0.003	0.064
T-11, SPB	0.74	0.106	6.95	0.062	-0.044	0.064
T-12, SPB	0.50	0.104	4.78	0.090	-0.014	0.064
T-13, SPB	0.65	0.105	6.23	0.069	-0.036	0.064
T-14, CS	0.38	0.1	3.80	0.113	0.013	0.064
T-15, CS	0.46	0.101	4.59	0.094	-0.007	0.064
T-16, SB	0.41	0.109	3.76	0.115	0.006	0.064
T-17, SB	0.45	0.08	5.58	0.077	-0.003	0.064
T-18	0.77	0.067	11.56	0.037	-0.030	0.064
T-19	0.78	0.064	12.12	0.036	-0.028	0.064
T-20	0.63	0.068	9.24	0.047	-0.021	0.064
T-21	0.73	0.07	10.49	0.041	-0.029	0.064
T-22, SB	0.42	0.072	5.86	0.073	0.001	0.064
T-23, SB	0.60	0.068	8.84	0.049	-0.019	0.064
T-24, SB	0.47	0.074	6.35	0.068	-0.006	0.064

[1] Color coding

Allowable $Se_{DISS.}$ < $Se_{DISS.}$ @ Freeport

Allowable $Se_{DISS.}$ > Measured $Se_{DISS.}$

[2] Station location coding: SPB = San Pablo Bay, CS = Carquinez Strait, SB = Suisun Bay

Part 2: Alternative Dissolved Se Criterion Value

The elements in an alternative approach to the development of an aqueous Se criterion value are shown in Figure 2. The alternative approach is based on the EPA Region 9/USGS approach shown in Figure 1 but with the substitution of the fish egg Se concentration for the target concentration and the substitution of a K_{RATIO} for the K_d parameter.

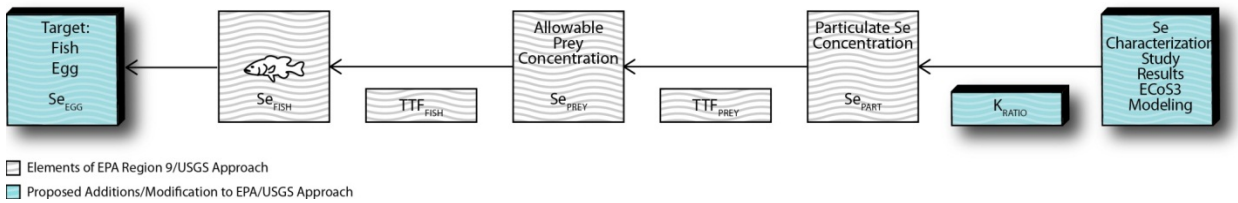

Figure 2. Steps in the proposed alternative approach for the translation of a tissue Se concentration in fish (target) to an allowable water-column Se concentrations.

The substitution of the fish egg criterion follows the lead of the ongoing efforts at US EPA Headquarters, also working on the development of a Se water quality criterion value that is based on fish egg or ovary Se concentration (not whole body). The Se concentration in eggs or embryos of fish is regarded as the most sensitive indicator of reproductive effects. In recent discussions, EPA Headquarters staff indicated that the fish egg concentration likely to be selected is between 15 and 20 µg/g. The substitution of the fish egg criterion means that an additional transfer factor is added to the development of the dissolved criterion value (i.e., the fish-egg concentration is translated into a fish muscle-tissue value). Using a larval toxicity threshold of 16.8 µg/g (based on the mean value from Linville (2006) and Tashjian et al. (2006)) and assuming a whole body:egg transfer factor of 1.41, then the whole body Se threshold for white sturgeon is 11.9 µg/g. This value is greater than the value for the white sturgeon that is used in the EPA Region 9/USGS approach. That value was 8.1 µg/g.

The pursuit of an alternative to the K_d parameter is based on the results of modeling efforts presented in Technical Memorandum 6 (TM6) prepared for the NSFB Se TMDL project (Tetra Tech, 2010) and recently presented in the peer-reviewed literature (Chen et al., 2012). The ECoS model provides a mechanistic basis for predicting Se concentrations in biota under a range of hydrologic and loading conditions. The model also provides a basis for relating Se loads, uptake rates, dissolved and particulate concentrations, and tissue concentrations. Two alternatives to the K_d approach, based on the modeling results presented in TM6 and Chen et al. (2012), were developed and evaluated. The first alternative is based on the development of Se species-specific relationships between particulate and dissolved selenium concentrations. For example, the following equations were developed to represent the predicted particulate Se concentrations using measured values of dissolved selenium species [selenite (SeIV), selenate (SeVI), organic selenide (Se-II)] and measured concentration of chlorophyll a (Chla) and total suspended material (TSM).

- Dry season
  - Part Se (ug/g) = 0.38 - 6.44*SeIV + 5.26*SeVI - 2.6*Se-II + 0.7*(Chla/TSM); r^2 = 0.45
- Wet season
  - Part Se (ug/g) = 0.01 - 15.76*SeIV + 6.65*SeVI + 3.33*Se-II + 2.59*(Chla/TSM); r^2 = 0.49

The second alternative established a relationship between particulate Se concentrations and the concentrations of dissolved Se species weighted by their potential for uptake (estimated through the ECoS model and laboratory data). For example:

Part Se = [(SeVI)+4*(SeIV)+2(Se-II)]*K_{ratio}

Where K_{RATIO} is estimated by season and salinity range and developed for NSFB using available data.

Initial results using these alternative approaches showed that the allowable dissolved selenium concentrations could be in the range of 0.14–0.2 µg/l. For comparison, the average of the allowable dissolved Se concentrations based on the EPA Region 9/USGS approach (presented in Table 1) was 0.074 µg/l.

These initial results show that that alternative approaches can result in a dissolved Se criterion concentration that is greater than the EPA Region 9/USGS values by a factor of 2 or 3. It is also important to note that the calculations based on the alternative approach are almost always greater than the measured dissolved Se in NSFB. This finding serves as evidence of the existence of assimilative capacity for selenium (i.e., the capacity to receive waste waters containing Se without deleterious effects on aquatic species).

Part 3: Alternative Particulate Se Criterion Value

The use of a particulate Se concentration as an alternative to the EPA Region 9/USGS allowable dissolved Se concentration was also evaluated. Initial analyses showed that the use of a particulate Se concentration criterion value suffers from the same constraint as a dissolved Se criterion value (i.e., the resulting allowable particulate Se concentration values are very low and approximately equal to or in some cases less than the existing ambient concentrations measured in the estuary). An explanation for this result, a further examination of the importance of particulate selenium in the EPA Region 9/USGS approach, and specific assessments with regard to the nature of the refinery effluents are presented below.

As shown in Figure 3, the explanation for the low values for the allowable dissolved or particulate Se concentrations in the EPA Region 9/USGS approach or the alternative approaches that we have explored is the highly efficient uptake of Se by the invasive clam *Corbula amurensis*. The uptake of Se by the clam has been parameterized and incorporated into the USGS ecosystem-scale Se modeling approach. The highly efficient uptake of Se by this clam is reported to have been measured in the field by USGS (Presser and Luoma, 2010a) and is discussed further in Part 4 below.

Representative dissolved and particulate water-column Se concentrations are presented in Frames I and II of Figure 3. The allowable particulate Se concentration is back-calculated (as previously shown in Figure 1) using the USGS-derived trophic transfer factor (TTF_{clam} value = 17). The allowable dissolved Se concentration is then back-calculated from the allowable particulate Se concentration using the USGS-derived K_d value. Figure 3 shows the importance of the TTF_{clam} value in the development of either an allowable dissolved or allowable particulate Se concentration in the water column:

- *C. amurensis* has demonstrated the ability to filter large volumes of water and to concentrate Se in the tissue. The TTF_{clam} value is calculated as the product of an assimilative efficiency value (AE), an ingestion rate value (IR), and an excretion or loss term ($1/k_e$). The USGS uses a TTF_{clam} value of 17 for a series of modeling scenarios presented in the Administrative Report (Presser and Luoma, 2010a) cited by EPA. While different assumptions regarding the values of AE, IR or k_e can result in a range of TTF_{clam} values (Presser and Luoma (2010a) cites a range of 14 – 26), this large magnification of the particulate Se concentration from the suspended particulate matter to the clam tissue is the reason the allowable particulate or allowable dissolved concentrations will be low and at or near background values.
- The allowable particulate concentration shown in Frame II of Figure 3 is 0.43 µg/g Se, which multiplied by 17 and 1.1 gives the target adult white sturgeon target tissue concentration value of 8.0 µg/g Se.

- For comparison (also shown in Figure 3), the average particulate Se concentration measured in San Pablo Bay in the 2011 Dry Season sampling event was 0.58 µg/g. The measured particulate Se concentration measured at Freeport in the 2011 Dry Season Sampling event was 1.42 µg/g.

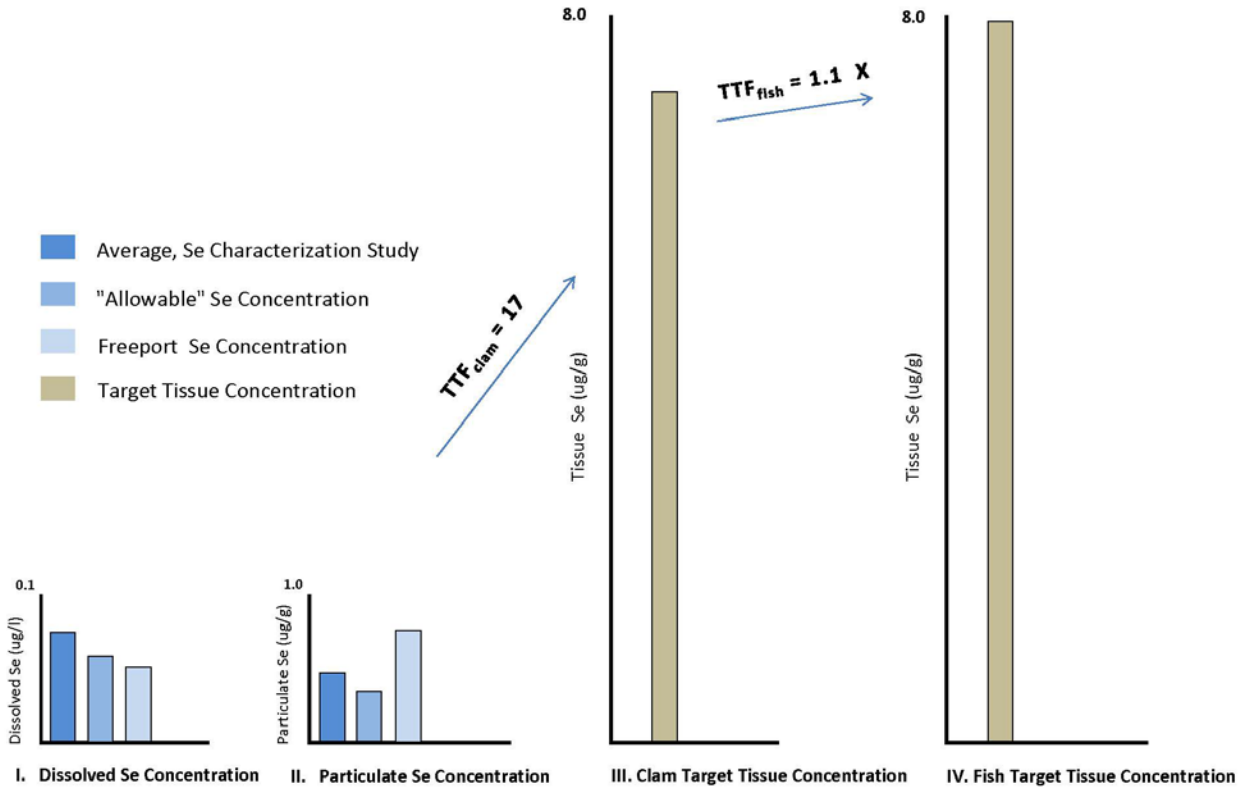

Figure 3. Measured or specified target aqueous and tissue concentrations of Se in North San Francisco Bay. Measured dissolved and particulate concentrations are average values measured in the 2011 dry season sampling conducted as part of the Se Characterization Study (Tetra Tech, 2012).

Examination of Particulate Se Concentrations in the Refinery Effluent

With this initial information on an alternative particulate Se criterion value, it's important to look at the nature of the particulate concentrations in the refinery effluent. The average particulate Se concentration measured in the refinery effluent as part of the Se Characterization Study was 54.8 µg/g. This value is significantly higher that the initial estimate of an allowable particulate Se concentration (0.43 µg/g). The high particulate Se concentration (when expressed in terms of mass per unit mass, µg/g) in the effluent is due, in part, to the low total suspended material concentrations in the refinery effluent (which averages 6.45 mg/l compared with 16.4 mg/l in the NSFB receiving water).

The characteristics of the particulate Se concentrations in the effluent expressed as volumetric concentrations of particulates, expressed in units of µg/l, were also examined. The conversion of an allowable particulate Se target (µg/g) to volumetric particulate concentration (µg/l) is dependent upon the total suspended material (TSM) which may include both living and dead organisms and well as inorganic material. Table 2 shows the calculated allowable volumetric particulate Se concentrations (µg/l) for a range of TSM values.

Table 2
Calculated Allowable Volumetric Particulate Se Concentrations (µg/l)

Fish Target	Clam Target	Particulate Target (µg/g)	TSM (mg/l)	Particulate (µg/l)
8	7.27	0.43	10	0.0043
8	7.27	0.43	20	0.0086
8	7.27	0.43	30	0.0128
8	7.27	0.43	40	0.0171
8	7.27	0.43	50	0.0214

For the refinery effluent samples, the average particulate concentration over 53 samples from September 2010 to August 2011 is 0.25 µg/l.

Evaluation of the Proportion of Particulate Se Concentration in NSFB that is Attributable to the Uptake of Dissolved Se by Phytoplankton (i.e., a "Produced" Particulate Se Concentration)

While these initial analyses show that a particulate Se concentration criterion value could not be met by the refineries, the characteristics of the Se in the refinery effluent indicate that the contribution of the refinery effluent to the uptake by plankton and clams in NSFB is minimal. Almost all of the particulate Se in the refinery effluent is in the elemental form (Se0). The average over 53 samples for Se0 is 0.34 µg/l. Although the volumetric concentration is higher than the calculated target, the refinery effluent particulate selenium is of a form defined in the EPA Region 9/USGS methodology to have zero uptake into clams.

As part of these analyses, the proportion of particulate Se concentration in the estuary that is attributable to the uptake of dissolved Se by phytoplankton (i.e., a "produced" particulate Se concentration was calculated). The results, presented in Figure 4, are derived from a simplified steady-state model that utilized Se uptake and mineralization coefficient values from the ECoS3 modeling of Se in North San Francisco Bay (Chen et al., 2012).

The simulated conditions represent a conservative dry-weather case with an "in-Bay" water-residence time of 14 days and the calculation of the selenium in the particulate phase downstream of the dissolved Se from refinery-effluent sources. The calculated selenium in the particulate phase is shown for 1) background conditions at the eastern end of the estuary, 2) increased particulate Se concentrations due to phytoplankton growth at the downstream location, 3) increased particulate Se concentration due to dissolved uptake of Se during the 14-day residence time, and 4) the added component from the dissolved Se uptake due to the dissolved Se from the refinery effluent. These results show that the dissolved Se concentrations from the refinery effluent make a minor contribution to the Se concentrations in phytoplankton and to the Se concentrations in clams.

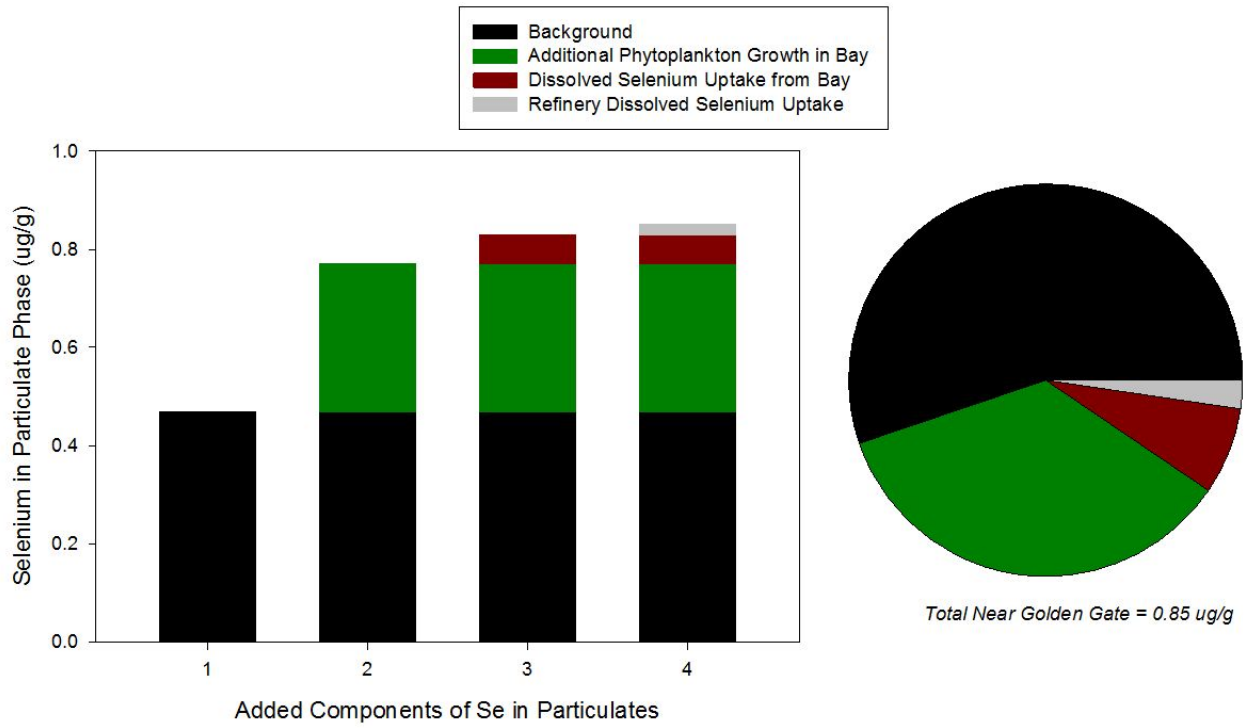

Figure 4. Results of the calculation of Se uptake in the estuary by phytoplankton. Assumptions: residence time of 14 days in cell near Golden Gate; Riverine chlorophyll a = 4 ug/l, and TSM = 10 mg/l; Bay eastern zone chlorophyll a = 2 ug/l, and TSM = 8 mg/l; Golden Gate chlorophyll a = 6 ug/l, and TSM = 7 mg/l.

Part 4: Consideration of Alternative Feeding Preferences

Another primary concern with the EPA Region 9/USGS approach presented in the 2010 USGS Administrative Report (Presser and Luoma, 2010a) is the assumption that the target fish, white sturgeon (*Acipenser transmontaus*), feeds exclusively on the invasive clam, *Corbula amurensis*. The consequence of the demonstrated ability of *C. amurensis* to filter large volumes of water and to concentrate Se is the assignment of a very high value for the trophic transfer factor (TTF_{clam}). As shown in Figure 3 Frame III, the high value of TTF_{clam} (17) results in a large magnification of the particulate Se concentration from the suspended particulate matter to the clam tissue. This large Se food-magnification value is the reason the allowable dissolved or allowable particulate concentrations, discussed in Parts 2 and 3, are low and near or below background values.

The sensitivity of the calculated value of the allowable dissolved Se concentration to the parameter values selected in the USGS ecosystem-scale methodology was recognized by the Presser and Luoma (2010b), and the effect of different TTF_{clam} values was explored. Table 3 shows TTF_{clam} values for different species of clams found in San Francisco Bay that were presented in the Presser and Luoma (2101b). It is also noteworthy that the value of TTF_{clam} for *Corbula amurensis* in Presser and Luoma (2010b) was 6.25, a value derived from laboratory studies. A field-derived TTF_{clam} value of 17 is presented and used to calculate the allowable dissolved Se concentrations in Presser and Luoma (2010a).

Table 3
TTFClam Values for Three Species of Clams in San Francisco Bay

Species	Source	TTF
Clam (*Corbicula fluminea*)	Presser and Luoma, Integrated Environmental Assessment and Management — Volume 6, Number 4—pp. 685–710, Table 3	2.8
Clam (*Macoma balthica*)	Presser and Luoma, Integrated Environmental Assessment and Management — Volume 6, Number 4—pp. 685–710, Table 3	4.5
Clam (*Corbula amurensis*)	Presser and Luoma, Integrated Environmental Assessment and Management — Volume 6, Number 4—pp. 685–710, Table 3	6.25
Clam (*Corbula amurensis*)	Presser and Luoma, EPA Administrative Report, 2010, page 24	17

Several calculations are presented in Table 4 to show the effects of varying the value of TTF_{clam} on the alternative allowable dissolved Se concentrations presented in Parts 2 and 3, above. The 18 analyses presented in Table 4 can be partitioned into two groups. The first group of analyses (1 – 9) used the fish-tissue concentration (8.0 µg/g) as the regulatory target. The second set of analyses (10 – 18) used a fish-tissue concentration of 11.9 µg/g, which corresponds to the calculation of the fish-tissue concentration based on the adoption of a larval toxicity criterion value. The derivation of the alternative fish-tissue concentration is described above in Part 2. In both sets of analyses, three different TTF_{clam} values were used in the calculation of the allowable particulate Se concentration and the allowable dissolved Se concentration:

- Analyses 1 – 3 and 10 – 12: The TTF_{clam} value is based on the assumption that the white sturgeon feeds on three clams (*Coricula fluminea, Macoma balthica, and Corbula amurensis*) in equal proportions. The TTF_{clam} values for each species is presented in Table 3, and the TTF value used in these analyses for C. amurensis is 6.25. The composite TTF_{clam} value is 4.52.
- Analyses 4 – 6 and 13 – 15: The TTF_{clam} value is based on the assumption that the white sturgeon feeds only on *Corbula amurensis*, and that the TTF_{clam} value is 6.25 (the laboratory-derived value).
- Analyses 7 – 9 and 16 – 18: The TTF_{clam} value is based on the assumption that the white sturgeon feeds only on *Corbula amurensis*, and that the TTF_{clam} value is 17 (the field-derived value). These analyses correspond closely to those shown above in Parts 1 and 2.

Table 4
Alternative Allowable Se Concentrations Calculated with Different TTFClam Values.

Analysis	Fish Target	Clam Target	TTF_{Clam}	Alternative Particulate Se (ug/g)	TSM (mg/l)	Alternative Particulate Se (ug/l)	Alternative Dissolved Se Se_{DISS} (ug/L)
1	8	7.27	4.52	1.61	10	0.0161	0.264
2	8	7.27	4.52	1.61	20	0.0322	0.264
3	8	7.27	4.52	1.61	30	0.0483	0.264
4	8	7.27	6.25	1.16	10	0.0116	0.191
5	8	7.27	6.25	1.16	20	0.0233	0.191
6	8	7.27	6.25	1.16	30	0.0349	0.191
7	8	7.27	17.0	0.43	10	0.0043	0.070
8	8	7.27	17.0	0.43	20	0.0086	0.070
9	8	7.27	17.0	0.43	30	0.0128	0.070
10	11.9	10.82	4.52	2.39	10	0.0239	0.392
11	11.9	10.82	4.52	2.39	20	0.0479	0.392
12	11.9	10.82	4.52	2.39	30	0.0718	0.392
13	11.9	10.82	6.25	1.73	10	0.0173	0.284
14	11.9	10.82	6.25	1.73	20	0.0346	0.284
15	11.9	10.82	6.25	1.73	30	0.0519	0.284
16	11.9	10.82	17.0	0.64	10	0.0064	0.104
17	11.9	10.82	17.0	0.64	20	0.0127	0.104
18	11.9	10.82	17.0	0.64	30	0.0191	0.104

The results of these analyses are presented in Table 4. Fixing the value of K_d for these analyses (6.102) provides a basis for comparing the effects of varying the value of TTF_{Clam}. The selected Kd value is the mean of the values calculated for San Pablo Bay (see Table 1) using the values of total particulate and dissolved concentrations measured in the 2011 dry season sampling event. It's evident from Figure 1 and Figure 3, which describe the steps in the calculation of the allowable dissolved Se concentrations, that the effect on the allowable dissolved Se concentration will be directly proportional to the change in the selected TTF_{Clam} value. For example, the results of Analysis 7 best represent the base case for an allowable dissolved Se concentration (0.07 µg/L) that was presented in the USGS Administrative Report (Presser and Luoma, 2010a). In that analysis the value of TTF_{Clam} was 17. For comparison, when the selected TTF_{Clam} value is 4.52 (Analysis 1), representing the feeding of white sturgeon on three clam species, the calculated allowable dissolved Se concentration is 0.264 (a factor of 17/4.52 = 3.76 difference). Also presented in Table 4 (e.g., Analyses 1 – 3) are the results of analyses that show the effect of changes in the TTF_{Clam} value on an allowable particulate Se concentration for different value of TSM. These results are directly comparable to the results of the first three analyses presented in Table 2.

Part 5: Findings

1. A primary concern with the EPA Region 9/USGS approach is the reliance on the partition coefficient (K_d) to derive the dissolved Se criterion concentration. This simple ratio of particulate to dissolved Se concentrations in the water column cannot be assumed to remain fixed over changing conditions, which may include, among other things, changing sources, phytoplankton

abundance and species, Se speciation and also seasonal and long-term hydrological changes.

As shown in Table 1, the calculated allowable dissolved Se concentration is generally below the dissolved Se concentrations measured in the Pacific Ocean as well as Sacramento River, an observation that demonstrates the limits of extrapolating from a linear model (between dissolved and particulate) to a concentration range that is not observed.

2. The initial evaluation of an alternative approach to the development of a dissolved Se criterion value resulted in the development of a dissolved Se criterion concentration that is greater than the EPA Region 9/USGS values by a factor of 2 or 3. This alternative approach is based on the results of published modeling results and takes into account the relationship between particulate Se concentrations and concentrations of dissolved species weighted by their potential for uptake. The alternative approach provides an allowable dissolved Se concentration that is almost always greater than the ambient dissolved Se concentrations in NSFB. This finding could be used by EPA and the Regional Water Quality Control Board as evidence of the existence of assimilative capacity (i.e., the capacity to receive waste waters or toxic materials without deleterious environmental effects).
3. The initial results from the evaluation of developing a particulate Se concentration criterion value show that a particulate Se criterion concentration suffers from the same constraint as a dissolved Se criterion concentration (i.e., the resulting allowable particulate Se concentration values are very low and approximately equal to or in some cases less than the existing ambient concentrations measured in the estuary).
4. Another primary concern with the EPA Region 9/USGS approach presented in the 2010 USGS Administrative Report (Presser and Luoma, 2010a) is the assumption that the target fish, white sturgeon (*Acipenser transmontaus*), feeds exclusively on the invasive clam, *Corbula amurensis*. Calculations presented in Table 4 show that the effect of assuming a wider selection of food items by the white sturgeon and/or the direct adjustment of the TTF_{Clam} value can affect the allowable particulate or dissolved Se concentrations by a factor of at least 3.76. This alternative approach, like the adoption of an alternative approach described in Part 2, provides an allowable dissolved Se concentration that is almost always greater than the ambient dissolved Se concentrations in NSFB and a value that supports the finding for the existence of assimilative capacity.
5. Two important findings from the recently developed refinery effluent data are that their contributions to the Se concentrations in phytoplankton and to the Se concentrations in clams are minimal:
    - Almost all of the particulate Se in the refinery effluent has been shown to be in the elemental form (Se0): a form defined in the EPA Region 9/USGS methodology to have zero uptake into clams.
    - Steady-state modeling results show that the dissolved Se concentrations from the refinery effluent makes a minor contribution to the Se concentrations in phytoplankton and to the Se concentrations in clams.

References

Chen, L., S.L. Meseck, S.B. Roy, T. M. Grieb, and B. Baginska. 2012. Modeling Fate and Transport of Selenium in North San Francisco Bay. Estuaries and Coasts 35(6):1551-1570.

Linville RG. 2006. Effects of excess selenium on the health and reproduction of white sturgeon (Acipenser transmontanus): Implications for [the] San Francisco Bay-Delta. PhD thesis submitted to the University of California at Davis.

Presser, T.S. and S.N Luoma. 2010a. Ecosystem-Scale Selenium Modeling in Support of Fish and Wildlife Criteria Development for the San Francisco Bay-Delta Estuary, California. Administrative Report, December 2010.

Presser, T.S. and S.N Luoma. 2010b. A Methodology for Ecosystem-Scale Modeling of Selenium. Integrated Environmental Assessment and Management 6(4):685-710.

Tashjian, D.H., S.J. Teh, A. Sogomonyan, S.S.O. Hung. 2006. Bioaccumulation and chronic toxicity of dietary L-selenomethionine in juvenile white sturgeon (Acipenser transmontanus). Aquatic Toxicology 79(4): 401–409.

Tetra Tech, Inc. 2010. Technical Memorandum #6: Application of ECoS3 for Simulation of Selenium Fate and Transport in North San Francisco Bay. http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/TMDLs/northsfbayselenium/TM-6_Modeling_Final_Report_02-10.pdf

Tetra Tech, Inc. 2012. North San Francisco Bay Selenium Characterization Study. Final Report. October 5, 2012.

USEPA, 2011. Water Quality Challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: Unabridged Advance Notice of Proposed Rulemaking. February 2011.

USEPA, 2012. Water Quality Challenges in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: EPA's Action Plan. August 2012.