Aquatic Life Ambient Water Quality

Criterion for

Selenium – Freshwater

EPA 822-R-16-006 (June 2016)

APPENDIX K: TRANSLATION OF A SELENIUM FISH TISSUE CRITERION ELEMENT TO A SITE-SPECIFIC WATER COLUMN VALUE

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

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1.0 TRANSLATING THE CONCENTRATION OF SELENIUM IN TISSUE TO A CONCENTRATION IN WATER USING MECHANISTIC BIOACCUMULATION MODELING

Introduction:

EPA recommends fish tissue elements of the selenium criterion supersede water column elements under steady state conditions because the selenium concentration in fish tissue is a more sensitive and reliable indicator of the negative effects of selenium in aquatic life. However, implementation of a fish tissue criterion element can be challenging because many state and tribal Clean Water Act (CWA) programs prefer the expression of water quality criteria as an ambient concentration in the water-column. Therefore, EPA also recommends two monthly average water-column criterion elements, one for lotic (flowing) waters, and the other for lentic (still) waters. EPA derived all water column criterion elements from the egg/ovary criterion element representing a protective selenium concentration for fish species populations. Thus the water column criterion elements also represent protective selenium concentrations for fish species populations. If threatened or endangered fish species are present, states and tribes may need to derive alternative water column elements with a refined protection goal that account for site-specific bioaccumulation characteristics.

EPA derived water-column criterion elements by modeling selenium bioaccumulation in aquatic systems. The EPA worked with the United States Geological Survey to derive a translation equation utilizing a mechanistic model of bioaccumulation previously published in peer-reviewed scientific literature (Luoma et. al., 1992; Wang et. al., 1996; Luoma and Fisher, 1997; Wang, 2001; Schlekat et al. 2002b; Luoma and Rainbow 2005; Presser and Luoma 2006; Presser and Luoma 2010; Presser 2013). EPA translated the selenium egg-ovary criterion element into two set(s) of site-specific water concentration values (lentic and lotic), and used the distribution(s) of those water column values to derive the respective water-column criterion elements. This appendix describes approaches that states and tribes may choose to use regarding application of this same mechanistic modeling approach (or alternatively an empirical bioaccumulation factor (BAF) approach) to translate a fish tissue criterion element (egg-ovary, whole body, or muscle) into site-specific water-column concentrations to more precisely manage selenium in specific aquatic systems.

The relationship between the concentration of selenium in the tissues of fish and the concentration of selenium in the water column can vary substantially among aquatic systems. The species of fish, the species and proportion of prey, and a variety of site-specific biogeochemical factors affect selenium bioaccumulation and thus determine the allowable concentration of selenium in ambient water protective of aquatic life. States and tribes may choose to adopt the results of site-specific water column translations as site-specific criteria (SSC) or adopt a translation procedure into state or tribal water quality standards. Under both options, the water quality standards revisions must be approved by EPA under Section 303(c) of the Clean Water Act. If a state or tribe adopts a translation procedure that will be implemented by other CWA programs, it must be scientifically defensible, produce repeatable, predictable outcomes, and result in criteria that protect the applicable designated use. Examples of such approaches include the mechanistic modeling approach and the empirical BAF approach described within this Appendix.

EPA considered both mechanistic and empirical modeling approaches to translate the selenium egg-ovary criterion element into water column concentration elements. A mechanistic modeling approach uses scientific knowledge of the physical and chemical processes underlying bioaccumulation to establish a relationship between the concentrations of selenium in the water column and the concentration of selenium in the tissue of aquatic organisms. The mechanistic modeling approach enables formulation of site-specific models of trophic transfer of selenium through aquatic food webs and translation of the egg-ovary criterion element into an equivalent site-specific water concentration. The empirical modeling approach establishes a relationship between concentrations of selenium in fish tissue and ambient water directly by measuring selenium concentrations in both media and calculating the ratio of the two concentrations. The ratio (BAF) can then be used to estimate the target concentration of selenium in the water column as related to the adopted fish tissue element.

Both the mechanistic and empirical modeling approaches have advantages and disadvantages that should be considered before deciding which approach to use. On the one hand, the mechanistic modeling approach has the advantage of not requiring extensive fish tissue sampling and analysis by using knowledge of aquatic system food webs. However, uncertainty in the selection of model parameters increases uncertainty in the outcome leading to a reduction in defensibility. Of particular concern with respect to the mechanistic model EPA developed is the selection of the value for the enrichment factor parameter EF (discussed in more detail below). On the other hand, the empirical BAF approach is conceptually and computationally simpler because it relies only on field measurements and does not require extensive knowledge of the physical, chemical, or biological characteristics of the aquatic system. However, obtaining a sufficient number of measurements in fish tissue and water may be logistically difficult and/or more expensive.

The appropriate modeling approach to use when translating the selenium egg-ovary criterion element to a site-specific water-column concentration depends on individual circumstances and site-specific characteristics. The mechanistic modeling approach may be a useful method in situations where there is little or no data on the amount of selenium in an aquatic system, the empirical BAF approach may be desirable in circumstances where in fish tissue and water data are available. Below is a description of methodology than can be used to translate the egg-ovary criterion element to a site-specific water-column concentration for site-specific management of selenium.

1.1 Relating the Concentration of Selenium in Fish Tissue and Water using the Mechanistic Modeling Approach

The relationship between the concentration of selenium in the eggs or ovaries of fish and the concentration of selenium in the water column is given in Equation K-1 (Equation 18 from the main text):

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite} \times EF \times CF} \qquad \textit{(Equation K-1)}$$

Where:

C_{water} = the concentration of selenium in water (µg/L),

$C_{egg\text{-}ovary}$ = the concentration of selenium in the eggs or ovaries of fish (µg/g),

$TTF^{composite}$ = the product of the trophic transfer factor (*TTF*) values of the fish species that is the target of the egg-ovary criterion element and the *TTF* values of all lower trophic levels in its food web (no units of measurement, see explanation below).

EF = the steady state proportional bioconcentration of dissolved selenium at the base of the aquatic food web (L/g),

CF = the species-specific proportion of selenium in eggs or ovaries relative to the average concentration of selenium in all body tissues (no units of measurement).

The basic principles expressed in Equation K-1 are illustrated in the conceptual model shown in Figure K-1.

Selenium dissolved in surface water enters aquatic food webs by becoming associated with trophic level 1 primary producer organisms (e.g., algae) and other biotic (e.g., detritus) and abiotic (e.g., sediment) particulate material. An enrichment function (*EF*) quantifies the bioconcentration of selenium in particulate material and thus its bioavailability in the aquatic system. The parameter *EF* is a single value that represents the steady state proportional concentration of selenium in particulate material relative to the concentration of selenium dissolved in water.

Organic particulate material is consumed by trophic level 2 organisms (usually aquatic invertebrates, but also some fish species that are herbivores/detritivores) resulting in the accumulation of selenium in the tissues of those organisms. Trophic level 2 invertebrates are consumed by trophic level 3 fishes resulting in further accumulation of selenium in the tissues of those fish. Bioaccumulation of selenium from one trophic level to the next is quantified by a trophic transfer factor (*TTF)*. A *TTF* is a single value that represents the steady state proportional concentration of selenium in the tissue of an organism relative to the concentration of selenium in the food it consumes. Different species of organisms metabolize selenium in different ways. Thus each species is associated with a specific *TTF* value. Because the trophic transfer of selenium through all trophic levels is mathematically equal to the product of the individual *TTF* values, all consumer-resource interactions in a particular aquatic ecosystem are simplified in Equation K-1 by representing the product of all the individual *TTF* values as the single parameter $TTF^{composite}$.

Fish accumulate selenium in different tissues of the body in differing amounts. Species physiology, age, diet, sex, and spawning status are some of the factors that affect selenium partitioning in body tissues. Because the primary selenium criterion element is expressed as a concentration in the eggs and/or ovaries, a conversion factor (*CF*) quantifies the relationship between the concentration of selenium in the eggs and/or ovaries and the average concentration of selenium in the whole body or muscle tissues. The parameter *CF* in Equation K-1 is a single value that represents the steady state proportional concentration of selenium in the eggs and/or ovaries relative to the average concentration of selenium in all body tissues. Different species of fish accumulate selenium in their eggs and ovaries to different degrees. Thus each species of fish is associated with a specific *CF* value.

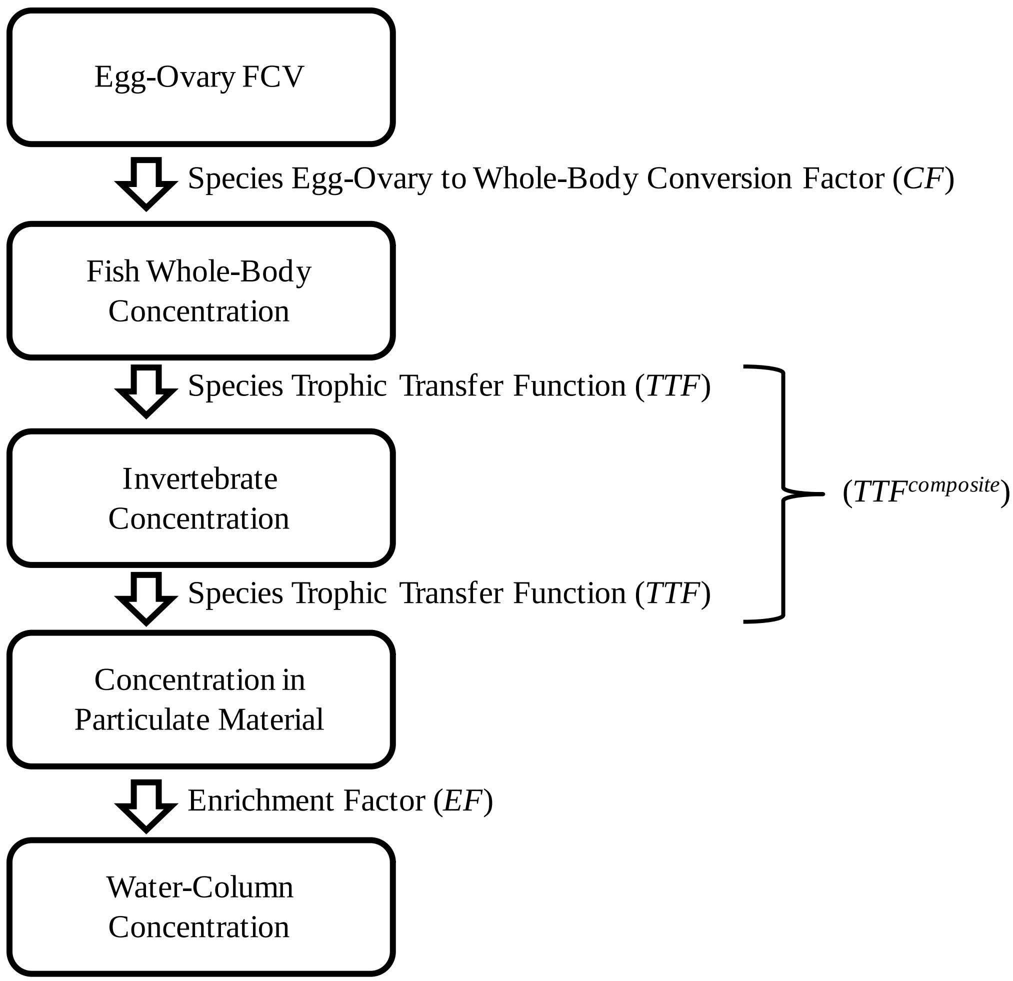


Figure K-1. Conceptual model for translating the egg-ovary FCV to a water-column concentration. Note: States may want to use the whole body or muscle criterion elements as the starting point for site specific translation to a water column concentration.

Once the parameters that quantify the transfer of selenium through each step in this pathway are identified, they can be used with Equation K-1 to translate the egg-ovary criterion element to a site-specific concentration of selenium in the water column (i.e., target water column concentration).

Because each *TTF* value is species-specific, it is possible to differentiate bioaccumulation in different aquatic systems by modeling the food web of the target fish species. For example, where the food web contains more than 3 trophic levels, $TTF^{composite}$ can be represented as the product of all *TTF* values for each trophic level given in Equation K-2, which is a generalization of Equation 10 from the main text:

$$TTF^{composite} = TTF^{TL2} \times TTF^{TL3} \times \ldots \times TTF^{TLn} \qquad \textit{(Equation K-2)}$$

Where:

$TTF^{composite}$ = the product of all *TTF* values at all trophic levels.

TTF^{TLn} = the *TTF* value of the highest trophic level.

The consumption of more than one species of organism at the same trophic level can also be modeled by expressing the *TTF* value at a particular trophic level as the average *TTF* values of all species at that trophic level weighted by the proportion of species consumed given as Equation K-3 (Equation 11 in the main text):

$$\overline{TTF}^{TLx} = \sum_i \left(TTF_i^{TLx} \times w_i \right) \qquad \textit{(Equation K-3)}$$

Where:

TTF_i^{TLx} = the trophic transfer factor of the ith species at a particular trophic level

w_i = the proportion of the ith species consumed.

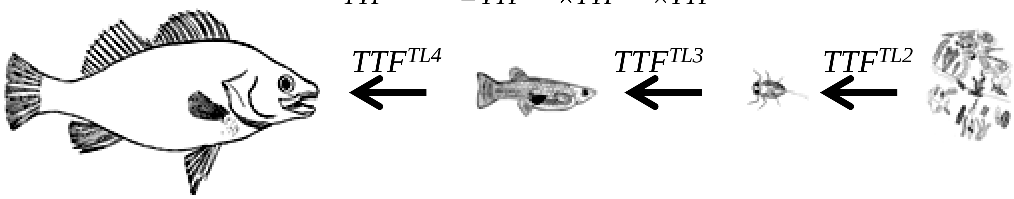
These concepts can be used to formulate a mathematical expression of $TTF^{composite}$ that models selenium bioaccumulation in a variety of aquatic ecosystems. Figure K-2 illustrates five hypothetical food web scenarios and the formulation of $TTF^{composite}$ for each of them. For each scenario, the value of $TTF^{composite}$, the *CF* value associated with the targeted fish species, and the site-specific *EF* value can be used with Equation K-1 to translate the egg-ovary criterion element to a site-specific water concentration value. The hypothetical food web models in Figure K-2 are a few possible examples of food web models for illustrative purposes. It is desirable to derive and use of a food web model that best represents the aquatic system for which the water column translation will apply. The general steps for deriving a site-specific translation of the egg-ovary criterion element to a water concentration value are described below.

A) Three trophic levels (simple):

$$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$$

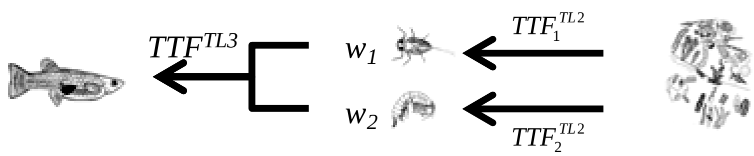
B) Four trophic levels (simple):

$$TTF^{composite} = TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2}$$



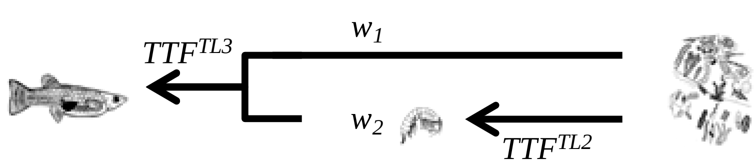
C) Three trophic levels (mix within trophic levels):

$$TTF^{composite} = TTF^{TL3} \times \left[\left(TTF_1^{TL2} \times w_1\right) + \left(TTF_2^{TL2} \times w_2\right)\right]$$



D) Three trophic levels (mix across trophic levels):

$$TTF^{composite} = \left(TTF^{TL3} \times w_1\right) + \left(TTF^{TL3} \times TTF^{TL2} \times w_2\right)$$



E) Four trophic levels (mix across trophic levels):

$$TTF^{composite} = \left[\left(TTF^{TL4} \times TTF^{TL3} \times w_1\right) + \left(TTF^{TL4} \times w_2\right)\right] \times TTF^{TL2}$$

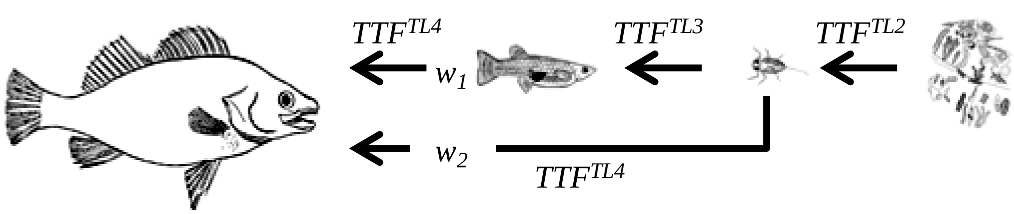


Figure K-2. Example mathematical expressions of $TTF^{composite}$ representing different food-web scenarios.

$TTF^{composite}$ quantitatively represents the trophic transfer of selenium through all dietary pathways of a targeted fish species. The mathematical expression of the food web model is used to calculate a value for $TTF^{composite}$ using appropriate species-specific *TTF* values and the proportions of each species consumed at each trophic level. See text for further explanation.

1.2 Steps for Deriving a Site-Specific Water Concentration Value from the Egg-Ovary Criterion Element

Below are the steps for deriving a site-specific water concentration value from the selenium egg-ovary criterion element using EPA's mechanistic model approach:

1) Identify the appropriate target fish species.
2) Model the food web of the targeted fish species.
3) Identify appropriate *TTF* values by either:
    a. selecting the appropriate *TTF* values from a list of EPA-derived values, or
    b. deriving *TTF* values from existing data, or
    c. deriving *TTF* values by conducting additional studies, or
    d. extrapolating *TTF* values from existing values.
4) Determine the appropriate value of *EF* by either
    a. deriving a site-specific *EF* value from field measurements, or
    b. deriving an appropriate *EF* value from existing data, or
    c. extrapolating from *EF* values of similar waters.
5) Determine the appropriate *CF* value by either,
    a. selecting the appropriate *CF* value from a list of EPA-derived values, or
    b. deriving a *CF* value from existing data, or
    c. deriving a *CF* value by conducting additional studies, or
    d. extrapolating a *CF* value from existing values.
6) Translate the selenium egg-ovary criterion element into a site-specific water concentration value using Equation K-1.

Below are detailed descriptions of each step followed by example calculations using a variety of hypothetical scenarios. EPA is providing this information to support help states and tribes that choose to develop selenium water column values from the egg-ovary criterion element or develop translation procedures. Successful application of the mechanistic approach described here requires use of particular food web models and parameter values that are appropriate for particular aquatic systems.

1.2.1 Identify the Appropriate Target Fish Species

1.2.1.1 When fish are present

In developing a site-specific translation of the egg-ovary criterion element, the user wshould select whether to use a mechanistic model or empricial (BAF) approach. This decision will in large part determine the data and information requirements. A mechanistic model approach will likely require information on the spatial and temporal distribution of aquatic organisms, and may require measurements of selenium in ambient water and particulate material. An empirical model approach will use measurements of selenium is fish tissue and ambient water.

Developing a site-specific translation of the egg-ovary criterion element will also entail selection of which species of fish to target. The concentration of selenium in eggs and ovaries is the most sensitive and consistent indicator of toxicity. However, toxicity and bioaccumulation potential can vary among species. Species in the families Acipenseridae, Centrarchidae, and Salmonidae are particularly sensitive to selenium (Table 3.3 in the main document), whereas species such as stoneroller species, creek chub, blackside dace, and white sucker have documented tolerance to selenium and can be found in selenium contaminated systems (NAMC 2008, Presser 2012). Green sunfish accumulate less selenium than other species with comparable exposures in the same aquatic system (Hitt and Smith 2015). Selection of the fish species in the aquatic system with the greatest selenium sensitivity and bioaccumulation potential is recommended.

Several additional factors should also be considered in deciding which species to target when developing a site-specific translation of the egg-ovary criterion element. Anadromous species (species that migrate from salt water to spawn in fresh water) should generally avoided because selenium exposure and bioaccumulation occurs over a relatively long period through the consumption of locally contaminated aquatic organisms. Additionally considerations include whether the fish species selected typically consume organisms known or suspected to readily bioaccumulate selenium (e.g., mollusks). For example, high concentrations of selenium in San Francisco Bay white sturgeon are associated with their consumption of *Potamocorbula amurensis*, a bivalve in close proximity to selenium-contaminated sediments that rapidly and efficiently accumulates selenium (Stewart et al. 2004). In contrast, striped bass from the same aquatic system have substantially lower concentration of selenium in their tissues because their zooplankton-based food web has substantially lower selenium bioaccumulation characteristics (Schlekat et al. 2004; Stewart et al. 2004). The 2016 selenium criterion was developed for freshwater, but if considering other ecosystems, it may be worth noting that salinity may also affect bioaccumulation of selenium. Freshwater mollusks tend to have relatively higher *TTF* values when compared to other freshwater invertebrate taxa (e.g., aquatic insects), but they are lower than mollusks in marine or brackish systems (and particularly *P*. *amurensis*, an invasive clam in the San Francisco Bay). In aquatic systems with resident fish species of unknown selenium sensitivity and bioaccumulation potential, other factors such as ecological significance could be considered when choosing a target species.

Data from fisheries or biological surveys or other biological assessments could be considered to determine the fish species that reside in specific surface waters. State and tribal resource agency personnel familiar with fish sampling activities could also be a source of information on resident fish species. General information on the fish species present in state and tribal surface waters may also be found at:

- State Fish and Game agencies
- U.S. Fish and Wildlife Service (http://www.fws.gov)
- U.S. Geological Survey (http://www.usgs.gov)
- NatureServe.org (http://www.natureserve.org)
- Fishbase (http://www.fishbase.org)
- State or local sources of biological information (e.g. Biota Information System of New Mexico at http://www.bison-m.org)

Measurements of selenium in fish tissue would most reflect the ecosystem if adult (reproductively mature) fish are sampled. Selenium measurements in fish tissue will likely be more stable in adult fish because they are more likely to have a stable prey base. Reproductively mature (ripe or gravid) females would be needed for measures selenium in eggs and/or ovary tissue for comparison to the the egg-ovary tissue criterion element. It would be prudent to avoid sampling ovary tissue “post-spawn” due to a potential decrease in selenium concentration presumably due to the loss of selenium through spawning and release of eggs with relatively high concentrations of selenium. Consideration of closely related taxonomic surrogates (same genus or family) for threatened or endangered species may be useful.

Figure K-3 shows an example decision tree that may help in selection of the appropriate fish species for deriving a site-specific water concentration value from the selenium egg-ovary, whole-body, or muscle FCV. The use of taxonomic hierarchies for anlysis utilizes evolutionary relationships to infer biological similarities among organisms (Suter 1993). Additional information on fish tissue sampling (e.g., species selection, temporal and spatial considerations) is under development and will be published in the form of a technical support document (TSD) by the EPA in the near future.

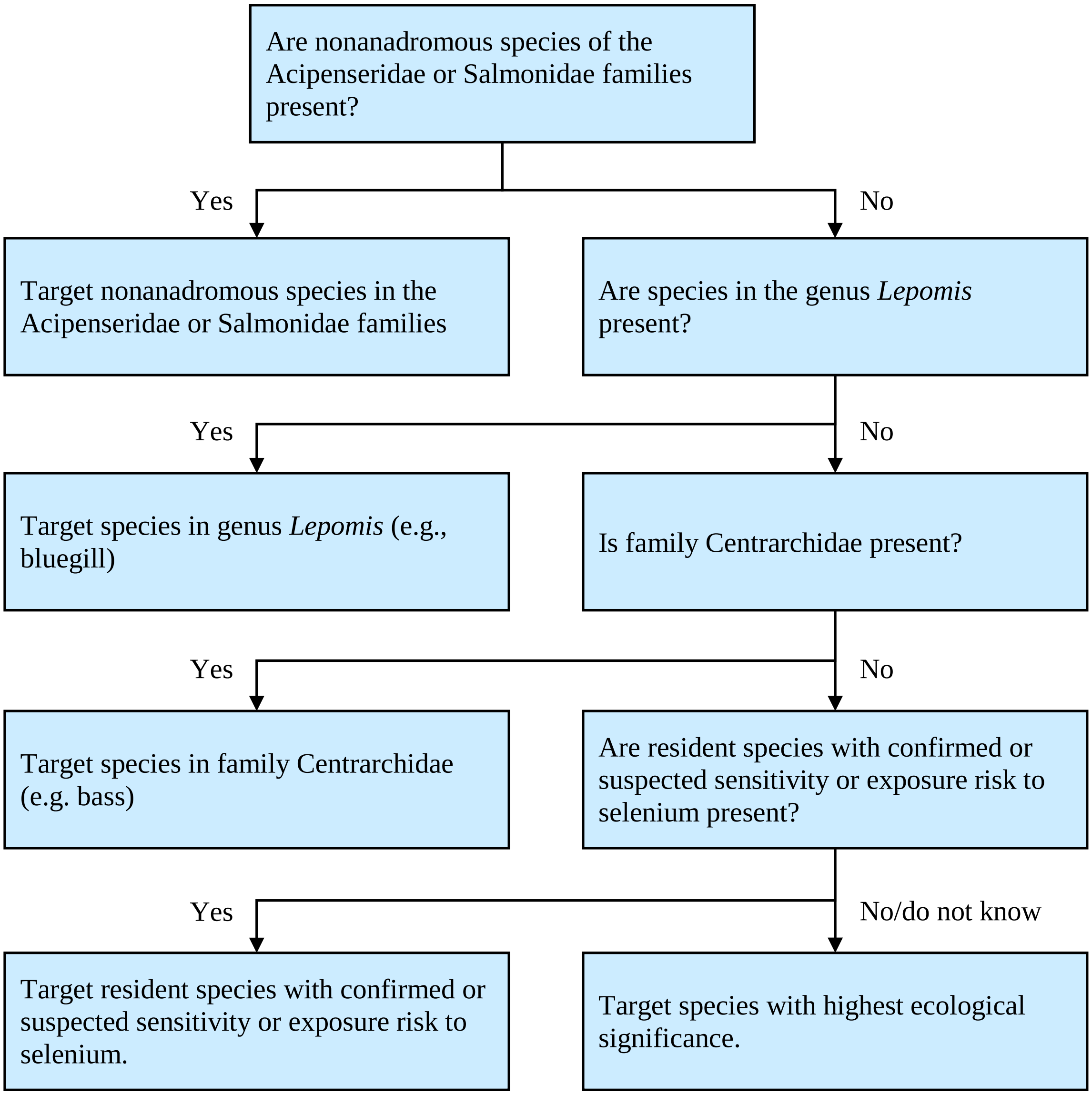


Figure K-3. Recommendeed decision process for selection of the fish species to use when deriving a water concentration from the selenium egg-ovary FCV.
This decision tree is also generally applicable when using the whole body or muscle tissue as the starting point for development of SSC, particularly when using the BAF approach.

1.2.1.2 When fish are absent from a site

Some aquatic systems do not contain resident fish. Fish may be absent from a waterbody because of intermittent or persistent low flows, physical impediments such as waterfalls or impoundments, lack of adequate habitat for feeding and/or spawning, or intolerable aquatic conditions related to pH, turbidity, temperature, salinity, total dissolved solids, chemical contaminants, or pathogens. These conditions could be due to natural or anthropogenic causes. Some streams may be naturally intermittent or ephemeral, or they might exhibit low or intermittent flows because of impoundments or water draw-down for agricultural irrigation, industrial uses, drinking water supply, or other uses.

When fish are absent from a waterbody, consideration of sampling the most sensitive fish species inhabiting nearby, most proximate downstream waters may be useful in order to understand selenium bioaccumulation potential in such systems. Although the upper reaches of some aquatic systems may not support fish communities, the invertebrate organisms that reside there may tolerate high concentrations of selenium and pose a selenium risk to predator fish if transported downstream. Users may choose to evaluate upstream waters without fish by measuring the selenium concentration in water, biotic and/or abiotic particulate material, and/or the tissues of invertebrate aquatic organisms that reside there. Because selenium associated with particulate material and invertebrate organisms can be transported downstream during intermittent high flows, elevated concentrations of selenium in the tissues of downstream fish could indicate upstream sources of selenium that require a more detailed evaluation of upstream conditions.

1.2.2 Model the Food-Web of the Targeted Fish Species

After selecting the target fish species, model users should formulate a mathematical expression of the target species food-web that will be used to calculate the value of $TTF^{composite}$. As discussed previously, $TTF^{composite}$ is the product of the *TTF* values across trophic levels of the target fish species food-web. The complexity of the food-web model will depend on the species of fish that is targeted, the diversity of prey species in the aquatic system, and the amount of information that is available. Many of the same information sources used to identify the targeted fish species in a waterbody could also be used to obtain information about its food web. The types and proportions of food organisms the targeted fish species consumes can be directly assessed through studies that examine stomach contents or from information gathered through biological assessments. If site-specific information is not available, model users could estimate the target fish species food-web using publicly available databases such as NatureServe (http://www.natureserve.org). For example, the NatureServe database record for fathead minnow in the HUC watershed #5040004 in Ohio indicates under the heading: “Ecology and Life History - Food Comments,” the fathead minnow “feeds opportunistically in soft bottom mud; eats algae and other plants, insects, small crustaceans, and other invertebrates (Becker 1983, Sublette et al. 1990).”

Additional sources of information include:

- FishBase (http://www.fishbase.org). FishBase is a relational database developed at the World Fish Center in collaboration with the Food and Agriculture Organization of the United Nations (FAO) and many other partners.

- Carlander, K.D. Handbook of Freshwater Fishery Biology, volumes 1, 2 and 3. Iowa state University Press, Ames, Iowa. 1969-1997.

1.2.3 Identify Appropriate *TTF* Values

The food-web model uses appropriately selected species-specific *TTF* values (and, if appropriate, proportions within the same trophic level). Model users identify the appropriate *TTF* values by using one of the following four procedures, or by using other scientifically defensible methods.

1.2.3.1 Select the appropriate *TTF* values from the provided list of EPA-derived values

Species-specific TTF values represent the steady state proportional concentration of selenium in the tissue of an organism relative to the concentration of selenium in the food it consumes. EPA-derived *TTF* values for aquatic invertebrates and fish are provided in Tables K-1 and K-2 (Tables 3.10 and 3.11 in main text; see also main text for a complete explanation of the procedure EPA used to derive these values).

Table K-1. EPA-derived Trophic Transfer Factor (TTF) values for freshwater aquatic invertebrates.
AE = Assimilation efficiency (%), IR = Ingestion rate (g/g-d), k_e = Elimination rate constant (/d).

Common name	Scientific name	AE	IR	k_e	TTF
Crustaceans					
amphipod	*Hyalella azteca*	-	-	-	1.22
copepod	copepods	0.520	0.420	0.155	1.41
crayfish	*Astacidae*	-	-	-	1.46
water flea	*Daphnia magna*	0.406	0.210	0.116	0.74
Insects					
dragonfly	*Anisoptera*	-	-	-	1.97
damselfly	*Coenagrionidae*	-	-	-	2.88
mayfly	*Centroptilum triangulifer*	-	-	-	2.38
midge	*Chironimidae*	-	-	-	1.90
water boatman	*Corixidae*	-	-	-	1.48
Mollusks					
asian clam[a]	*Corbicula fluminea*	0.550	0.050	0.006	4.58
zebra mussel	*Dreissena polymorpha*	0.260	0.400	0.026	4.00
Annelids					
blackworm	*Lumbriculus variegatus*	0.165	0.067	0.009	1.29
Other					
zooplankton	zooplankton	-	-	-	1.89

[a] Not to be confused with *Potamocorbula amurensis*

Table K-2. EPA-derived Trophic Transfer Factor (*TTF*) values for freshwater fish.
AE = Assimilation efficiency (%), IR = Ingestion rate (g/g-d), k_e = Elimination rate constant (/d).

Common name	Scientific name	AE	IR	k_e	TTF
Cypriniformes					
blacknose dace	*Rhinichthys atratulus*	-	-	-	0.71
bluehead sucker	*Catostomus discobolus*	-	-	-	1.04
longnose sucker	*Catostomus catostomus*	-	-	-	0.90
white sucker	*Catostomus commersonii*	-	-	-	1.11
flannelmouth sucker	*Catostomus latipinnis*	-	-	-	0.98
common carp	*Cyprinus carpio*	-	-	-	1.20
creek chub	*Semotilus atromaculatus*	-	-	-	1.06
fathead minnow	*Pimephales promelas*	-	-	-	1.57
red shiner	*Cyprinella lutrensis*	-	-	-	1.31
redside shiner	*Richardsonius balteatus*	-	-	-	1.08
sand shiner	*Notropis stramineus*	-	-	-	1.56
Cyprinodontiformes					
western mosquitofish	*Gambusia affinis*	-	-	-	1.21
northern plains killifish	*Fundulus kansae*	-	-	-	1.27
Esociformes					
northern pike	*Esox lucius*	-	-	-	1.78
Gasterosteiformes					
brook stickleback	*Culaea inconstans*	-	-	-	1.79

Common name	**Scientific name**	**AE**	**IR**	**k_e**	**TTF**
		Perciformes			
black crappie	*Pomoxis nigromaculatus*	-	-	-	2.67
bluegill	*Lepomis macrochirus*	-	-	-	1.03
green sunfish	*Lepomis cyanellus*	-	-	-	1.12
largemouth bass	*Micropterus salmoides*	-	-	-	1.39
smallmouth bass	*Micropterus dolomieu*	-	-	-	0.86
striped bass	*Morone saxatilis*	0.375	0.335	0.085	1.48
walleye	*Sander vitreus*	-	-	-	1.60
yellow perch	*Perca flavescens*	-	-	-	1.42
		Salmoniformes			
brook trout	*Salvelinus fontinalis*	-	-	-	0.88
brown trout	*Salmo trutta*	-	-	-	1.38
mountain whitefish	*Prosopium williamsoni*	-	-	-	1.38
cutthroat trout	*Oncorhynchus clarkii*	-	-	-	1.12
rainbow trout	*Oncorhynchus mykiss*	-	-	-	1.07
		Scorpaeniformes			
mottled sculpin	*Cottus bairdi*	-	-	-	1.38
sculpin	*Cottus sp.*	-	-	-	1.29
		Siluriformes			
black bullhead	*Ameiurus melas*	-	-	-	0.85
channel catfish	*Ictalurus punctatus*	-	-	-	0.68

The *TTF* values from these lists could be used exclusively, or in conjunction with *TTF* values obtained from other sources (see below). Note that these tables do not represent an exhaustive list of all *TTF* values that may be required to calculate a site-specific water concentration value. If this list does not include a required *TTF* value, another approach could be considered to obtain an appropriate value.

1.2.3.2 Deriving *TTF* values from existing data

If model users cannot obtain one or more required *TTF* values from Tables K-1 and/or K-2, species-specific *TTF* values could be derived using existing data. One approach for deriving species-specific *TTF* values is to use the physiological coefficients representing food ingestion rate (*IR)*, selenium efflux rate (k_e), and selenium assimilation efficiency (*AE*) to calculate a *TTF* value using Equation K-4 (Equation 3 from the main text, Reinfelder et al. 1998**)** given as:

$$TTF = \frac{AE \times IR}{k_e} \qquad \textit{(Equation K-4)}$$

Where:

TTF	=	species-specific trophic transfer factor
AE	=	species-specific assimilation efficiency (%)
IR	=	species-specific ingestion rate (g/g-d)
k_e	=	species-specific efflux rate constant (/d)

The physiological coefficients *IR*, *AE* and are species-specific values. Values for AE and k_e can only be derived from laboratory studies. Values for IR may be derived from laboratory studies or obtained from published literature. After the three physiological coefficients are obtained, a *TTF* value can be calculated using Equation K-4.

Another way to derive species-specific *TTF* values is to empirically assess the relationship between the selenium concentration in the tissue of organisms and the selenium concentration in the food they consume using paired measurements from field studies. Species-specific *TTF* values can be derived from such measurements by calculating ratios, using regression techniques, or other scientifically defensible methods.

Model users could choose to use the same approach EPA used to calculate species-specific *TTF* values. EPA derived *TTF* values using a combination median and regression approach. EPA defined the *TTF* value for any trophic level as:

$$TTF^{TLn} = \frac{C_{tissue}^{TLn}}{C_{food}^{TLn}} \qquad \textit{(Equation K-5)}$$

Where:

TTF^{TLn}	= The trophic transfer factor of a given trophic level,
C_{tissue}^{TLn}	= The selenium concentration (mg/kg dw) in the tissues of the consumer organism,
C_{food}^{TLn}	= The selenium concentration (mg/kg dw) in the consumer organism's food.

EPA used the median of the ratios given in Equation K-5 as the species-specific *TTF* value, but only if an empirical relationship between the paired measurements could be confirmed by linear regression analysis. EPA considered the relationship acceptable if a linear regression of tissue selenium concentration on food selenium concentration resulted in both a statistically significant fit ($P < 0.05$) and a positive slope (i.e., selenium concentrations in the consumer increases with increasing selenium in food).

1.2.3.3 Deriving *TTF* values by conducting additional studies

Additional studies could be conducted to obtain the data needed to derive *TTF* values for specific needs, or to revise existing *TTF* values, if the existing *TTF* values do not appear to be appropriate for a particular aquatic system.

1.2.3.4 Extrapolating *TTF* values from existing values

If one or more necessary *TTF* values are not available, and the information needed to derive a species-specific *TTF* value is not available or impractical to obtain, model users could consider extrapolating a new *TTF* value from other known *TTF* values. One possible method to extrapolate a *TTF* value is to sequentially consider higher taxonomic classifications until one or more of the organisms with a known *TTF* value matches the taxon being considered. If the lowest matching taxon is common to more than one of the available *TTF* values, the average *TTF* from the matching table entries could be used. The use of taxonomic hierarchies in this way utilizes evolutionary relationships to infer biological similarities among organisms (Suter 1993).

EPA used such an extrapolation approach to derive some of the *TTF* values necessary to develop the water column criterion elements. For example, the *TTF* value for *Chrosomus eos* (northern redbelly dace) was not available. *TTF* values were also not available for other species in the genus *Chrosomus*, but *TTF* values were available for species in the family Cyprinidae, including *Rhinichthys atratulus* (blacknose dace), *Cyprinus carpio* (common carp), *Semotilus atromaculatus* (creek chub), *Pimephales promelas* (fathead minnow), *Cyprinella lutrensis* (red shiner), *Richardsonius balteatus* (redside shiner), and *Notropis stramineus* (sand shiner). Because Cyprinidae is the lowest taxonomic classification where *Chrosomus eos* matches one or more species with an available *TTF* value, EPA used the median *TTF* value of blacknose dace, common carp, creek chub, fathead minnow, red shiner, redside shiner, and sand shiner as the *TTF* value for northern redbelly dace.

1.2.4 Determine the Appropriate *EF* Value

The selenium enrichment function (*EF*) value represents the bioavailability of selenium at the base of the aquatic food web. The base of the aquatic food web includes phytoplankton, periphyton, detritus, inorganic suspended material, biofilm, sediment and/or attached vascular plants (Presser and Luoma, 2010). EPA refers to this mixture of living and non-living entities as particulate material. The parameter *EF* varies more widely across aquatic systems than any other parameter, and is influenced by the source and form of selenium, water residence time, the biogeochemical characteristics of the waterbody, and the type of particulate matter collected. Because *EF* can vary greatly across waterbodies, this parameter has the greatest potential to introduce uncertainty in the translation from an egg-ovary selenium concentration to a water column concentration. For this reason, use *EF* values derived from site-specific data is recommended whenever possible in applying the model. One of the following four procedures could be used to derive *EF* values, or other scientifically defensible methods could be used.

1.2.4.1 Deriving a site-specific *EF* value from field measurements

Equation 12 from the main text defines the parameter *EF* as the ratio of the concentration of selenium in particulate material to the concentration of selenium dissolved in water given as:

$$EF = \frac{C_{particulate}}{C_{water}} \qquad \textit{(Equation K-6)}$$

Where:

$C_{particulate}$	=	Concentration of selenium in particulate material (µg/g)
C_{water}	=	Concentration of selenium dissolved in water (µg/L)
EF	=	Enrichment Function (L/g)

To calculate a site-specific *EF* value, EPA first calculates the ratio of each individual particulate measurement and its associated water measurement (if more than one water measurement is available for any given particulate measurement, the median water measurement is used). If more than one ratio for any given category of particulate material is available (e.g., more than one ratio of algae to water), EPA takes the median of the ratios. EPA then calculates the geometric mean of the median ratios for each category of particular material as the site *EF* value. EPA only uses sediment measurements if there are at least one measurement from either algae or detritus.

Deriving a site-specific *EF* value in this manner is a relatively straightforward procedure. However, consideration of data that appropriately accounts for the spatial and temporal variability of an aquatic system would be useful in the development of any sampling plan. Aquatic system characteristics such as dimension, volume, shape, residence time, velocity, and growing season are a few important factors that should be considered in designing a sampling plan that will adequately account for variability. State and Federal agencies (USGS, ACOE) as well as watershed groups may be useful sources of information that can help characterize the temporal and spatial variability at a particular aquatic system. When developing the selenium criterion, EPA observed a relatively lower correlation between the selenium concentration in water and abiotic (benthic sediments) particulate samples compared to the same analysis between water and biotic (algae and detritus) particulate samples, resulting in EPA's decision that calculation of any site-specific *EF* values include information from at least one type of biotic particulate indeveloping its criteiron. Prioritization of sampling of biotic particulate material over abiotic samples should be considered. Regaridng selenium measurements from abiotic particulate material, consideration of utilizing at least one type of biotic particulate material when deriving the *EF* value of an aquatic system is recommended.

Site-specific *EF* values using particulate and water samples that are as spatially and temporally coincident as possible would be considered the most robust. Although EPA's analysis of particulate and water samples from a sample population of aquatic systems found that samples taken within one year of each other, based on data availability, were appropriate in deriving the national criterion (Figure 3.5 in the main document), a site-specific EF value would ideally involve collecting particulate and water samples at the same location and time to ensure their representativeness of sirte-specific conditions. One simple and effective sampling and analysis scenario would be to collect water samples or a combination of particulate and water samples, separate the particulate material from the water in each sample by filtering, measure the concentration of selenium in the separated water and particulate material, compute the ratio of the two measurements from each sample, and then calculate the mean or median of all the ratios.

Selenium bioaccumulation occurs more readily in aquatic systems with longer residence times (such as lakes, reservoirs, oxbows, and wetlands) and with fine particulate sediments high in organic carbon. A well-planned sampling protocol was developed in association with the development of a site-specific water-column criterion for selenium in the San Francisco Bay Delta[2]. States and tribes may also want to consult Doblin et al. (2006) for specific particulate sampling methods. EPA's National Rivers and Streams Assessment[3] also provides methods for quantitative periphyton sampling that commonly represents the base of many aquatic food webs. Analytical methods to measure selenium in particulate material and in water are discussed in Appendix L.

1.2.4.2 Deriving an appropriate *EF* value from existing data

If suitable and sufficient site-specific measurements of selenium in particulate material and water are already available, the model user may be able to use that data to derive an appropriate *EF* value. However, it would be important to ensure that the data represents current conditions, were collected and analyzed using scientifically sound sampling and analytical techniques, and proper quality assurance and quality control protocols were implemented.

1.2.4.3 Extrapolating from *EF* values of similar waters

[2] https://www3.epa.gov/region9/water/ctr/selenium-modeling_admin-report.pdf
[3] https://www.nemi.gov/methods/method_summary/12558/ (EPA-841-B-07-009) and https://www.nemi.gov/methods/method_summary/12565/ (EPA-841-B-12-009)

In circumstances where a site-specific, field-derived *EF* value is not available or practical to develop, an *EF* value from one or more aquatic systems with similar hydrological, geochemical, and biological characteristics could be used to estimate *EF*. However, there is a possibility of introducing significant uncertainty when using *EF* values extrapolated from other aquatic systems. More information on this topic is contained in Appendix H of this document.

1.2.5 Determine the Appropriate *CF* Value

<u>1.2.5.1 Selecting the appropriate *CF* value from the list of values that were used to derive EPA's recommended water criteria concentration values</u>

The parameter *CF* represents the species-specific proportion of selenium in eggs or ovaries relative to the average concentration of selenium in all body tissues. EPA derived species-specific *CF* values for 20 species of fish from studies that measured selenium concentrations in both eggs and/or ovaries and in whole body and/or muscle. These *CF* values can be found in Appendix B and are reproduced below (Table K-3).

Table K-3. Selenium Whole Body to Egg-Ovary Conversion Factors (*CF*).

Common name	Median ratio (Cegg-ovary/ Cwhole-body)	Median ratio (Cegg-ovary/ Cmuscle)	Muscle to whole-body correction factor	Final CF values
Species				
Bluegill	2.13			2.13
Bluehead sucker	1.82			1.82
Brook trout		1.09	1.27	1.38
Brown trout	1.45			1.45
Creek chub	1.99			1.99
Common carp	1.92			1.92
Cutthroat trout	1.96			1.96
Desert pupfish	1.20			1.20
Dolly Varden		1.26	1.27	1.61
Fathead minnow	1.40			1.40
Flannelmouth sucker	1.41			1.41
Green sunfish	1.45			1.45
Mountain whitefish		5.80	1.27	7.39
Northern pike		1.88	1.27	2.39
Rainbow trout		1.92	1.27	2.44

Common name	Median ratio (Cegg-ovary/ Cwhole-body)	Median ratio (Cegg-ovary/ Cmuscle)	Muscle to whole-body correction factor	Final CF values
Razorback sucker		2.31	1.34	3.11
Roundtail chub	2.07			2.07
Smallmouth bass	1.42			1.42
White sturgeon		1.33	1.27	1.69
White sucker	1.38			1.38
Genus				
Catostomus				1.41
Gila				2.07
Lepomis				1.79
Micropterus				1.42
Oncorhynchus				1.96
Family				
Catostomidae				1.41
Centrarchidae				1.45
Cyprinidae				1.95
Salmonidae				1.71
Order				
Cyprinodontiformes				1.20
Perciformes				1.45
Class				
Actinopterygii				1.45

The data and methods used to derive the *CF* in this table are described in Appendix B.

1.2.5.2 Deriving a *CF* value from existing data

The parameter *CF* is mathematically expressed as Equation K-7 (Equation 16 in the main text):

$$CF = \frac{C_{egg-ovary}}{C_{whole-body}} \qquad \textit{(Equation K-7)}$$

Where:

CF	=	Whole-body to egg-ovary conversion factor (dimensionless ratio).
$C_{egg\text{-}ovary}$	=	Selenium concentration in the eggs or ovaries of fish (µg/g)
$C_{whole\text{-}body}$	=	Selenium concentration in the whole body of fish (mg/kg).

If suitable and sufficient data are available, a model user could derive a species-specific *CF* value using the same numerical methods described above to calculate the parameter *EF*. The median of the ratios given in Equation K-7 could be used as the species-specific *CF* value, but only if an empirical relationship between the paired measurements could be confirmed by linear regression analysis. IN deriving the national criterion, EPA considered it to be acceptable if a linear regression of egg-ovary selenium concentration on whole body selenium concentration resulted in both a statistically significant fit ($P < 0.05$) and a positive slope. Other scientifically defensible methods could be used. Regardless of the method used, the user should ensure that the data used to derive *CF* values were collected using adequate quality assurance and quality control protocols.

1.2.5.3 Deriving a *CF* value by conducting additional studies

Additional studies could be performed to obtain data needed to derive *CF* values for specific needs or to revise existing *CF* values if there is reason to believe doing so may increase the accuracy of the resulting water concentration value. Analytical methods to measure selenium in tissue are discussed in Appendix L. Where appropriate, additional data could be obtained as part of a NPDES permit application by invoking authority under CWA section 308 (or comparable state or tribal authority) to require NPDES-regulated facilities to collect information necessary to develop permit limits**.**

1.2.5.4 Extrapolating the CF value from the list of values that were used to derive EPA's recommended water criteria concentration values

If one or more necessary *CF* values are not available, and the information needed to derive a species-specific *CF* value is not available or impractical to obtain, a model user could could consider extrapolating a new *CF* value from other known *CF* values. One possible method to extrapolate a *CF* value is to use the same taxonomic approach EPA uses for *TTF* values that are not available for specific species (Section 1.2.3.4). Sequentially consider higher taxonomic classifications could be considered until one or more of the fish species with a known *CF* value matches the taxon being considered. If the lowest matching taxon is common to more than one of the available *CF* values, the average *CF* value from the matching table entries could be used.

1.2.6 Translate the Selenium Egg-Ovary Criterion Element into a Site-Specific Water Concentration Value using Equation K-1

Model users could derive a site-specific water concentration value from the egg-ovary criterion element value using Equation K-1 with appropriate values of *CF*, $TTF^{composite}$ (derived from the product of the individual *TTF* values from each trophic level) and *EF*. Note that NPDES permitting regulations at 40 CFR § 122.45(c) requires that a Water Quality-Based Effluent Limit (WQBEL) for metals be expressed as total recoverable metal, unless an exception is met under 40 CFR § 122.45(c)(1)-(3). Equation K-1 assumes selenium concentrations dissolved in water. While states and tribes may express ambient water quality criteria in water quality standards as dissolved selenium, an additional step would be necessary to convert the dissolved selenium concentration to a total recoverable selenium concentration for the purpose of NPDES permitting. Guidance for converting expression of metal concentrations in water from dissolved to total recoverable can be found in *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) and *The Metals Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion* (U.S. EPA 1996).

1.3 Managing Uncertainty using the Mechanistic Modeling Approach

Uncertainty in the translation of the egg-ovary criterion element to a water column value using the mechanistic bioaccumulation modeling approach (Equation K-1) can arise from several sources. These include:

- Measurement error when deriving input parameters,
- Inaccurate food web models due to misidentification and/or incorrect proportions of prey organisms,
- Inaccurate or inappropriate *EF*, *TTF*, and/or *CF* values,
- Biological variability,
- Unaccounted factors affecting bioaccumulation (e.g. selenium speciation), and
- Other unknown factors.

The most influential step in selenium bioaccumulation occurs at the base of aquatic food webs (Chapman et al. 2010). The parameter *EF* characterizes this step by quantifying the partitioning of selenium between the dissolved and particulate state. *EF* can vary by at least two orders of magnitude across aquatic systems (Presser and Luoma 2010). The greatest reduction in uncertainty could be achieved when translating a fish tissue concentration of selenium to a water column concentration using Equation K-1 by using temporally and spatially coincident site-specific empirical observations of dissolved and particulate selenium of sufficient quality and quantity to accurately characterize *EF*.

Presser (2013) provides several recommendation to reduce uncertainty in an ecosystem scale approach to deriving a site-specific selenium water column criterion in a coal mining impacted area of West Virginia. Suggested actions to reduce uncertainty include:

- Obtaining temporally matched pairs of selenium measurements in dissolved and particulate material across a broad range of sites to ensure the samples accurately characterize the aquatic system and to assess sample variability;
- Characterizing particulate material across seasons to better define the base of the food web;
- Evaluating aquatic systems variables such as residence time, watershed dilution, and physical habitat attributes on as fine a scale as possible;
- Refining model assumptions to accurately characterize dietary preferences and composition of fish, and develop additional *TTF* values if necessary;
- Identify and target fish species particularly sensitive to selenium;
- Consider temporal changes in the bioaccumulation potential of the aquatic system and changes in selenium sensitivity over the life cycle of fish; and
- Consider variability in hydrology and selenium discharges.

The suitability of selected equation parameters could be determined by obtaining fish tissue and water column measurements of selenium from small-scale field studies, use of equation K-1 to estimate one measurements using the other, and comparison of the estimated concentration with the actual concentration (see Section 6.2.1 of the main document for a description of EPA's validation approach).

1.4 Example Calculations

Below are six hypothetical examples that demonstrate how to translate the egg-ovary FCV to a site-specific water concentration criterion using Equation K-1. These examples encompass a variety of hypothetical aquatic systems with various fish species and food webs. For these hypothetical examples, species-specific *TTF* values were taken from Tables K-1 and K-2, and *CF* values were taken from Table K-3. To calculate EF in these examples, the EPA used a hypothetical water concentration of 5 µg/L and the hypothetical particulate concentrations of 4.25 µg/g and 8.75 µg/g in lotic and lentic aquatic systems, respectively.

1.4.1 Example 1

Bluegill (*Lepomis macrochirus*) in a river that consume mostly amphipods:

Current water concentration (µg/L)	5.00
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor for bluegill (TTF^{TL3})	1.03
Trophic transfer factor for amphipods (TTF^{TL2})	1.22
Egg-ovary to whole-body conversion factor for bluegill (CF)	2.13
Selenium egg-ovary FCV (mg/kg)	15.1

$$\mathrm{EF} = \frac{\mathrm{C_{particulate}}}{\mathrm{C_{water}}}$$

$$EF = \frac{4.25}{5.00}$$

$$= 0.85 \text{ L/g}$$

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$$
$$= 1.03 \times 1.22$$
$$= 1.26$$

$$C_{water} = \frac{15.1}{1.26 \times 0.85 \times 2.13}$$

$$= 6.62\ \mu\text{g/L}$$

1.4.2 Example 2

Fathead minnow (*Pimephales promelas*) in a river that consume mostly copepods:

Current water concentration (µg/L)	5.00
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor for fathead minnow (TTF^{TL3})	1.57
Trophic transfer factor for copepods (TTF^{TL2})	1.41
Egg-ovary to whole-body conversion factor for fathead minnow (CF)	1.40
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

$= 0.85$ L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$$

$= 1.57 \times 1.41$

$= 2.21$

$$C_{water} = \frac{15.1}{2.21 \times 0.85 \times 1.40}$$

$= 5.74$ µg/L

1.4.3 Example 3

Bluegill (*Lepomis macrochirus*) in a lake that consume mostly aquatic insects:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	8.75
Trophic transfer factor for bluegill (TTF^{TL3})	1.03
Trophic transfer factor for aquatic insects (median of Odonates, Water boatman, Midges, and Mayflies) (TTF^{TL2})	2.14
Egg-ovary to whole-body conversion factor for bluegill (CF)	2.13
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{8.75}{5.00}$$

= 1.75 L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$
= 1.03 x 2.14
= 2.20

$$C_{water} = \frac{15.1}{2.20 \times 1.75 \times 2.13}$$

= 1.84 µg/L

1.4.4 Example 4

Fathead minnow (*Pimephales promelas*) in a river that consume approximately ⅔ copepods and ⅓ aquatic insects:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor for fathead minnow (TTF^{TL3})	1.57
Trophic transfer factor for copepods and aquatic insects (TTF^{TL2}) Copepods = 1.41 Average of all aquatic insects = 2.14 $TTF^{TL2} = \sum_{i=1}^{n}\left(TTF_i \times w_i\right)$ = (1.41 × ⅔) + (2.14 × ⅓) = 1.65	1.65
Egg-ovary to whole-body conversion factor for fathead minnow (CF)	1.40
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$TTF^{composite} = TTF^{TL3} \times TTF^{TL2}$
= 1.57 × 1.65
= 2.59

$$C_{water} = \frac{15.1}{2.59 \times 0.85 \times 1.40}$$

= 4.90 µg/L

1.5.5 Example 5

Flathead chub (*Platygobio gracilis*) in a river with a diet of approximately 80% aquatic insects and 20% algae:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor of flathead chub: Lowest matching taxon is the family Cyprinidae. Therefore, the TTF value of Cyprinidae is used (TTF^{TL3})	1.20
Trophic transfer factor for insects (TTF^{TL2}) Average of all aquatic insects = 2.14	2.14
Egg-ovary to whole-body conversion factor for flathead chub (species-specific value not available, so median CF for family Cyprinidae is used). (CF)	1.95
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$TTF^{composite} = [TTF^{TL3} \times TTF^{TL2} \times w_1] + [TTF^{TL3} \times w_2]$$

Where:
w_1 = Proportion of fathead chub diet from insects; and
w_2 = Proportion of fathead chub diet from algae

$$TTF^{comb} = [1.20 \times 2.14 \times 0.8] + [1.20 \times 0.2]$$
$$= 2.29$$

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$$C_{water} = \frac{15.1}{2.29 \times 0.85 \times 1.95}$$

= 3.98 µg/L

1.5.6 Example 6

Largemouth bass (*Micropterus salmoides*) in a large river that consume mostly Western mosquitofish (*Gambusia affinis*) that consume approximately ¾ insects and ¼ crustaceans:

Current water concentration (µg/L)	5.0
Current particulate concentration (mg/kg)	4.25
Trophic transfer factor of largemouth bass (TTF^{TL4})	1.39
Trophic transfer factor of Western mosquitofish (TTF^{TL3})	1.21
Trophic transfer factor for insects and crustaceans (TTF^{TL2}) Median all Insects – 2.14 Median all Crustaceans – 1.41 $TTF^{TL2} = \sum_{i=1}^{n}\left(TTF_i^{TL2} w_i\right)$ = (2.14 x 0.75) + (1.41 x 0.25) = 1.96	1.96
Egg-ovary to whole-body conversion factor for largemouth bass (species-specific value not available, so median CF for genus Micropterus is used) (CF)	1.42
Selenium egg-ovary FCV (mg/kg)	15.1

$$EF = \frac{C_{particulate}}{C_{water}}$$

$$EF = \frac{4.25}{5.00}$$

= 0.85 L/g

$$TTF^{composite} = TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2}$$
$$= 1.39 \times 1.21 \times 1.96$$
$$= 3.30$$

$$C_{water} = \frac{C_{egg-ovary}}{TTF^{composite}\ x\ EF\ x\ CF}$$

$$C_{water} = \frac{15.1}{3.30 \times 0.85 \times 1.42}$$

= 3.79 µg/L

2.0 TRANSLATING THE CONCENTRATION OF SELENIUM IN TISSUE TO A CONCENTRATION IN WATER USING BIOACCUMULATION FACTORS (BAF)

2.1 Summary of the BAF Approach

A bioaccumulation factor (BAF) is the ratio (in milligrams/kilogram per milligrams/liter, or liters per kilogram) of the concentration of a chemical in the tissue of an aquatic organism to the concentration of the chemical dissolved in ambient water at the site of sampling (U.S. EPA 2001c). BAFs are used to relate chemical concentrations in aquatic organisms to concentrations in the ambient media of aquatic ecosystems where both the organism and its food are exposed and the ratio does not change substantially over time. The BAF is expressed mathematically as:

$$BAF = \frac{C_{tissue}}{C_{water}}$$

(Equation K-8)

Where:

BAF	=	bioaccumulation factor derived from site-specific field-collected samples of tissue and water (L/kg)
C_{tissue}	=	concentration of chemical in fish tissue (mg/kg)
C_{water}	=	ambient concentration of chemical in water (mg/L)

The site-specific BAF can then be applied to the tissue criterion to solve for a target site-specific water column criterion (C_{target}):

$$C_{target} \times \frac{C_{egg-ovary\ criterion}}{BAF}$$

(Equation K-9)

Where:

C_{target}	=	site-specific water criterion concentration (mg/L)
$C_{egg\text{-}ovary\ criterion}$	=	national egg-ovary tissue criterion (15.1 mg Se/kg dw)
BAF	=	bioaccumulation factor derived from site-specific field-collected samples of tissue and water (L/kg)

To translate a fish tissue criterion to a water concentration value, a site-specific, field-measured BAF for the waterbody could be developed, and then a water concentration criterion could be calculated using Equation K-9. Detailed information about how to derive a site-specific, field-measured BAF is provided in *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume 3: Development of Site-specific Bioaccumulation*

Factors (U.S. EPA 2009). Although this guidance was developed for deriving human health criteria, the methodological approach is also applicable to the derivation of aquatic life criteria. The following example illustrates the calculation of a site specific water column criterion using the BAF approach.

2.1.1 Example: Derivation of a site specific water column criterion for a waterbody impacted by selenium

Available data for a hypothetical site indicate that the average egg/ovary tissue concentration of selenium for the bluegill (*Lepomis macrochirus*) is 22 mg/kg (dw). This concentration exceeds the USEPA proposed egg/ovary criterion of 15.1 mg/kg (dw). The ambient selenium water column concentration at that hypothetical site is 4.0 µg/L. The following calculation shows how to derive a target water column that would achieve a site-specific criterion using the bioaccumulation factor (BAF) approach.

Site specific selenium egg/ovary concentration (bluegill; mg/kg dw)	22.0
Selenium egg/ovary criterion (mg/kg, dw)	15.1
Ambient selenium water column concentration (µg/L)	4.0
Target water column concentration (µg/L)	X

Set up proportional equation to solve for allowable water column concentration:

$$\frac{Site\ specific\ egg/ovary\ conc.\ (\frac{mg\ Se}{kg\ dw})}{Site\ specific\ water\ concentration\ (\frac{\mu g\ Se}{L})} = \frac{Criterion\ egg\ ovary\ conc.\ (\frac{mg\ Se}{kg\ dw})}{Target\ water\ concentration\ (\frac{\mu g\ Se}{L})}$$

Solve for the target water concentration that will achieve a site-specific criterion:

$$\frac{22.0\ (\frac{mg\ Se}{kg\ dw})}{4.0\ (\frac{\mu g\ Se}{L})} = \frac{15.1\ (\frac{mg\ Se}{kg\ dw})}{Target\ water\ concentration\ (\frac{\mu g\ Se}{L})}$$

Target water concentration = 2.75 µg/L.

2.2 Managing Uncertainty using the BAF Approach

Uncertainty can be introduced when using the BAF approach to derive a water concentration value from a fish tissue criterion concentration. Inaccurate water concentration values can result when BAFs are derived from water and fish tissue concentration measurements that are obtained from sources that do not closely represent site characteristics, or from field data collected from large-scale sites that encompass multiple water bodies or ecosystems. Most of this uncertainty results from differences in the bioavailability of selenium between the study sites where measurements are made to derive the BAF, and the site(s) to which the BAF is used to derive needed water concentration values.

Because of uncertainties associated with the BAF approach, EPA does not recommend developing BAFs from data extrapolated from different sites or across large spatial scales. EPA's Framework for Metals Risk Assessment (U.S. EPA 2007) outlines key principles about metals and describes how they should be considered in conducting human health and ecological risk assessments due the the effects of water chemistry on bioavilability of such chemicals. The current science does not support the use of a single, generic threshold BAF value as an indicator of metal bioaccumulation. The use of BAFs are appropriate only for site-specific applications where sufficient measurements have been taken from the site of interest and there is little or no extrapolation of BAF values across differing exposure conditions and species.

The preferred approach for using a BAF to implement the selenium fish tissue criterion is to calculate a site-specific, field-measured BAF from data gathered at the site of interest, and to apply that BAF to that site. A site-specific, field-measured BAF is a direct measure of bioaccumulation in an aquatic system because the data are collected from the aquatic ecosystem itself and thus reflects real-world exposure through all relevant exposure routes. A site-specific, field-measured BAF also reflects biotic and abiotic factors that influence the bioavailability, biomagnification, metabolism, and biogeochemical cycling of selenium that might affect bioaccumulation in the aquatic organism or its food web. Appropriately developed site-specific, field-measured BAFs are appropriate for all bioaccumulative chemicals, regardless of the extent of chemical metabolism in biota from a site (U.S. EPA 2000).

Although a site-specific, field-measured BAF is a direct measure of bioaccumulation, its predictive power depends on a number of important factors being properly addressed in the design of the field sampling effort. For example, sampling in areas with relatively long water residence times should be a priority because selenium bioaccumulation occurs more readily in aquatic systems with longer residence times (such as wetlands, oxbows, and estuaries) and with fine particulate sediments high in organic carbon. In addition, migratory species should generally not be used because their exposure to selenium could reflect selenium concentrations in areas other than where the fish were caught. Fish may also need to be sampled and BAF values recalculated if selenium levels significantly change over time because BAFs are known to be affected by the ambient concentration of the metals in the aquatic environment (McGeer et al. 2003; Borgman et al. 2004; DeForest et al. 2007). States and tribes should refer to *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume* (U.S. EPA 2009) for guidance on appropriate methods for developing a site-specific, field-derive BAF.

The advantage of using the BAF approach is its relative simplicity, especially when the data necessary to derive the BAF is already available. Furthermore, the BAF approach is completely empirical and does not require any specific knowledge about the physical, chemical, or biological characteristics of the waterbody. The relationship between the concentration of selenium in fish tissue and water is directly determined by direct measurements in these media. This may be advantageous when there are uncertainties with how to collect a particulate sample that is representative of the base of the food web, or dilution concerns (e.g., sandy streams with little surface area for algae sampling and high potential for sand contamination of a benthic sediment sample).

Limitations of the BAF approach should be considered before deciding if this method is appropriate for translating the selenium FCV to a water concentration value. One disadvantage of the BAF approach is the considerable effort and resources necessary to collect sufficient data to establish the relationship between tissue and water concentrations. Resource use increases as the spatial scale and complexity of the aquatic system increases. Furthermore, the BAF approach does not allow extrapolation across species, space, and large time scales because the site-specific factors that might influence bioaccumulation are integrated within the tissue concentration measurements and thus cannot be individually adjusted to extrapolate to other conditions. Thus, site-specific, field-measured BAFs only provide an accounting of the uptake and accumulation of selenium for an organism at a specific site and point in time. This is more important in lotic habitats, since the kinetics of selenium bioaccumulation may be very different at a site upstream or downstream from the site of interest.

As noted previously, NPDES permitting regulations at 40 CFR § 122.45(c) require WQBELs for metals be expressed as total recoverable metal unless an exception is met under 40 CFR § 122.45(c)(1)-(3). Guidance for converting expression of metals in water from dissolved to total recoverable can be found in *Technical Support Document for Water Quality-based Toxics Control* (U.S. EPA 1991) and *The Metals Translator: Guidance for Calculating a Total Recoverable Permit Limit from a Dissolved Criterion* (U.S. EPA 1996). Whether or not a water concentration value derived from a site-specific, field-derived BAF requires conversion from dissolved to total recoverable selenium depends on how the BAF is developed. Generally, conversion would not be necessary if the BAF is derived from water concentration values that measure total selenium; however, conversion would be necessary if the BAF was derived from water concentration values that measured dissolved selenium. Table K-4 compares some of the principle characteristics of the mechanistic bioaccumulation modeling approach or the BAF approach for translating the selenium FCV to a water concentration.

3.0 Comparison of Mechanistic Bioaccumulation Modeling and BAF Approaches

Data from Saiki et al. (1993) are used here to illustrate an example comparison of the two translation approaches, the mechanistic bioaccumulation modeling approach and the bioaccumulation factor (BAF) model approach. Definitive selenium measurements for all ecosystem compartments (e.g., water, algae, etc.) are available for two species, bluegill and largemouth bass, at four sites. Food web pathways were calculated using results of gut content analysis. Although Saiki et al. (1993) satisfies the minimum requirements for a site specific translation, it represents a sparse dataset, with only two measurements per ecosystem compartment, one for the spring and fall of 1987, respectively. For purposes of this exercise, samples from the same site collected at different time periods will be treated as replicate data; however, EPA recommends using larger sample sizes collected during the same time period when calculating a site specific criterion.

Selenium data used to calculate site specific water criteria are included in Table K-4. Median concentrations and coefficients of variation for each ecosystem compartment at each site are included in Table K-5. Because at most only two concentrations were available for each ecosystem, site median are equal to site averages. Site specific translations for both approaches will be calculated using median selenium concentrations.

Table K-4. Selenium concentrations in ecosystem compartments for four sites described in Saiki et al. (1993).
Water concentrations expressed as µg/L, all other concentrations expressed as mg/kg dw.

Site	Date	Water	Algae	Detritus	Amphipod	Chironomid	Crayfish	Zooplankton	Bluegill	Largemouth Bass
Mud Slough at Gun Club Road	Fall 1987	3	7.40	22	4.6	8.9	5.2	2.4	6.4	6.8
Mud Slough at Gun Club Road	Spring 1987	9	1.60	7.9	3.3	7.2	4.4	5.4	5	6.9
Salt Slough at the San Luis National Wildlife Refuge	Fall 1987	3	0.38	8.9	3.4	5.4	3.1	4.5	4.5	4.7
Salt Slough at the San Luis National Wildlife Refuge	Spring 1987	13	2.40	7.9	3.7	6.9	3.2	4.4	4.3	4
San Joaquin R. above Hills Ferry Road	Fall 1987	3	1.20	6.6	3.8	6	1.7	2.6	3.3	2.2
San Joaquin R. above Hills Ferry Road	Spring 1987	11	1.30	3.4	2.8	4.1	1.9	4.3	2.7	2.4
San Joaquin R. at Durham Ferry State Recreation Area	Fall 1987	1	0.39	1.2	1.5	1.5	0.77	1.6	2	1.8
San Joaquin R. at Durham Ferry State Recreation Area	Spring 1987		0.50	1.3	1.1	1.6	1.3	1.8	1.9	1.7

Table K-5. Median selenium concentrations in ecosystem compartments for four sites described in Saiki et al. (1993).
For purposes of this exercise, spring and fall samples measured at the same site are treated as replicates. Water concentrations expressed as µg/L, all other concentrations expressed as mg/kg dw. Coefficients of determination included in parentheses.

Site	Water	Algae	Detritus	Amphipod	Chironomid	Crayfish	Zooplankton	Bluegill	Largemouth Bass
Mud Slough at Gun Club Road	6.0 (0.71)	4.50 (0.91)	14.95 (0.67)	3.95 (0.23)	8.05 (0.15)	4.80 (0.12)	3.90 (0.54)	5.70 (0.17)	6.85 (0.01)
Salt Slough at the San Luis National Wildlife Refuge	8.0 (0.88)	1.39 (1.03)	8.40 (0.08)	3.55 (0.06)	6.15 (0.17)	3.15 (0.02)	4.45 (0.02)	4.40 (0.03)	4.35 (0.11)
San Joaquin R. above Hills Ferry Road	7.0 (0.81)	1.25 (0.06)	5.00 (0.45)	3.30 (0.21)	5.05 (0.27)	1.80 (0.08)	3.45 (0.35)	3.00 (0.14)	2.30 (0.06)
San Joaquin R. at Durham Ferry State Recreation Area	1.0 (na)	0.45 (0.17)	1.25 (0.06)	1.30 (0.22)	1.55 (0.05)	1.04 (0.36)	1.70 (0.08)	1.95 (0.04)	1.75 (0.04)

3.1 Translation using the BAF Approach

Site specific BAFs were calculated for bluegill and largemouth bass at each of the four sites (Table K-6). A site-specific water criterion was calculated for each species at the four sites using equation K-8, which is equivalent to the BAF example shown in the previous section. The site specific criterion calculation for bluegill at site "Salt Slough at the San Luis National Wildlife Refuge" is included below as an example.

$$BAF = \frac{C_{tissue}}{C_{water}} = \frac{4.4\ \mu g/g}{8\ \mu g/L} = 0.55\ L/g$$

$$C_{water\ criterion} = \frac{C_{tissue\ criterion}}{BAF} = \frac{8.5\ mg/kg}{0.55\ L/g} = 15.5\ \mu g/L$$

The whole body tissue criterion of 8.5 mg/kg is used here because whole body fish tissue selenium measurements were made. If site specific egg ovary fish tissue had been measured, then the egg ovary tissue criterion of 15.1 mg/kg would have been used.

Table K-6. Site and species specific translated water concentrations using the BAF translation approach.

		Bluegill:			**Largemouth Bass:**		
Site	**Water (µg/L)**	**WB Se (mg/kg)**	**BAF (L/g)**	**Water SSC[a] (µg/L)**	**WB Se (mg/kg)**	**BAF (L/g)**	**Water SSC[a] (µg/L)**
Mud Slough at Gun Club Road	6.0	5.70	0.95	8.95	6.85	1.14	7.45
Salt Slough at the San Luis National Wildlife Refuge	8.0	4.40	0.55	15.45	4.35	0.54	15.63
San Joaquin R. above Hills Ferry Road	7.0	3.00	0.43	19.83	2.30	0.33	25.87
San Joaquin R. at Durham Ferry State Recreation Area	1.0	1.95	1.95	4.36	1.75	1.75	4.86

a – Site specific criterion based on BAF for respective species.

At each site, the lowest translated water criterion for all species is used as the site specific criterion. At site "Mud Slough at Gun Club Road," the site specific criterion is based on the translated concentration for largemouth bass, and at the other 3 sites, the site specific criterion is based on the translated concentration for bluegill. Site specific water concentrations calculated using the BAF approach range from 4.4 to 19.8 µg/L Table K-6).

3.2 Translation using the Mechanistic Bioaccumulation Modeling Approach

The first step in the bioaccumulation modeling approach is the calculation of site specific enrichment factors (*EF*s). Because both algae and detritus selenium concentrations were available, the first step was the calculation of separate *EF*s for algae and detritus at each site, following the procedures described in section 1.2.4.1. Algal and detrital *EF*s, respectively, were calculated using the median of all Se concentrations in algae (or detritus) at a site by the median of all Se concentrations in water at the same site. After calculating separate algal and detrital *EF*s, the final *EF* at each site was calculated as the geometric mean of the algal and detrital *EF* at a given site. Algal, detrital, and site *EF*s are shown in Table K-7.

Table K-7. Se concentrations in water, algae, detritus, and site specific *EF*s.

Site	Water (µg/L)	Algae (mg/kg)	Detritus (mg/kg)	EF (L/g)
Mud Slough at Gun Club Road	6.0	4.50	14.95	1.37
Salt Slough at the San Luis National Wildlife Refuge	8.0	1.39	8.40	0.43
San Joaquin R. above Hills Ferry Road	7.0	1.25	5.00	0.36
San Joaquin R. at Durham Ferry State Recreation Area	1.0	0.45	1.25	0.75

As an example, the EF calculation for site "Salt Slough at the San Luis National Wildlife Refuge" is shown below.

$$EF_{algae} = \frac{C_{algae}}{water}\ ;\ EF_{detritus} = \frac{C_{detritus}}{water}$$

$$EF_{site} = \sqrt{(EF_{algae} \times EF_{detritus})}$$

$$EF_{algae} = \frac{1.39\ mg/kg}{8.0\ \mu g/L};\ EF_{detritus} = \frac{8.4\ mg/kg}{8.0\ \mu g/L}$$

$$EF_{site} = \sqrt{(0.17 \times 1.05)}$$

$$EF_{site} = 0.43\ L/g$$

The second step in the bioaccumulation modeling approach is the calculation of site specific composite trophic transfer factors ($TTF^{composite}$). Based on gut content analysis, bluegill diets consisted of

47% amphipods, 23% chironomids, and 30% zooplankton, while largemouth bass diets consisted of 73% bluegill and 27% crayfish.

The composite TTF for bluegill was calculated using the following equation:

$$TTF^{composite} = [TTF^{TL3} \times TTF^{TL2} \times w_1] + [TTF^{TL3} \times TTF^{TL2} \times w_2] + [TTF^{TL3} \times TTF^{TL2} \times w_3]$$

Where:

W_1 = proportion of diet from amphipods,

W_2 = proportion of diet from chironomids, and

W_3 = proportion of diet from zooplankton.

For each of the 3 species in the bluegill diet, site specific TTF^{TL3} and TTF^{TL2} were calculated separately. Using median concentrations from Table K-5, $TTF^{composite}$ were calculated for each of the sites and are included in Table K-8.

Table K-8. Trophic transfer factors (TTFs) for bluegill and bluegill prey.

	TL2 TTFs:			TL3 TTFs:			$\mathbf{TTF^{composite}}$:
Site	**Amphipod**	**Chironomid**	**Zooplankton**	**BG-Amph**	**BG-Chiro**	**BG-Zoo**	**Bluegill**
Mud Slough at Gun Club Road	0.41	0.83	0.40	1.44	0.71	1.46	0.59
Salt Slough at the San Luis National Wildlife Refuge	0.73	1.26	0.91	1.24	0.72	0.99	0.90
San Joaquin R. above Hills Ferry Road	1.06	1.62	1.10	0.91	0.59	0.87	0.96
San Joaquin R. at Durham Ferry State Recreation Area	1.53	1.83	2.01	1.50	1.26	1.15	2.30

As an example, the bluegill $TTF^{composite}$ for site "Salt Slough at the San Luis National Wildlife Refuge" is shown below.

$$TTF^{composite} = [1.24 \times 0.73 \times 0.47] + [0.72 \times 1.26 \times 0.23] + [0.99 \times 0.91 \times 0.30]$$

$$TTF^{composite} = 0.90$$

The composite TTF for largemouth bass was calculated using the following equation:

$$TTF^{composite} = [TTF^{TL4} \times TTF^{TL3} \times TTF^{TL2} \times w_1] + [TTF^{TL3} \times TTF^{TL2} \times w_2]$$

Where:

W_1 = proportion of diet from bluegill, and

W_2 = proportion of diet from crayfish

For the proportion of the largemouth bass diet consisting of bluegill, TTF^{TL3} x TTF^{TL2} was equal to the $TTF^{composite}$ for bluegill. As was the case for bluegill, site specific TTFs were calculated for each species, and are included in Table K-9.

Table K-9. Trophic transfer factors (TTFs) for largemouth bass and largemouth bass prey.

	Crayfish dietary fraction:		**Bluegill dietary fraction:**		**$TTF^{composite}$:**
Site	**Crayfish**	**LMB-Cray**	**Bluegill[a]**	**LMB-BG**	**LMB**
Mud Slough at Gun Club Road	0.49	1.43	0.59	0.70	0.49
Salt Slough at the San Luis National Wildlife Refuge	0.64	1.38	0.90	0.89	0.82
San Joaquin R. above Hills Ferry Road	0.58	1.28	0.96	0.74	0.71
San Joaquin R. at Durham Ferry State Recreation Area	1.22	1.69	2.30	2.06	4.03

a – $TTF^{composite}$ for bluegill.

As an example, the largemouth bass $TTF^{combined}$ for site "Salt Slough at the San Luis National Wildlife Refuge" is shown below.

$$TTF^{composite} = \left[TTF^{TL4} \times TTF^{composite}_{bluegill} \times w_1\right] + [TTF^{TL3} \times TTF^{TL2} \times w_2]$$

$$TTF^{composite} = [0.89 \times 0.90 \times 0.73] + [1.38 \times 0.64 \times 0.27]$$

$$TTF^{composite} = 0.82$$

After calculating site and species specific EF and $TTF^{combined}$, site specific water criterion concentrations were calculated using a modified version of equation K-1, shown below.

$$C_{water\ criterion} = \frac{C_{tissue\ criterion}}{EF\ x\ TTF^{composite}}$$

The site specific criterion calculation for bluegill at site "Salt Slough at the San Luis National Wildlife Refuge" is included below as an example.

$$C_{water\ criterion} = \frac{8.5\ mg/kg}{0.43\ L/g\ x\ 0.90} = 22.1\ \mu g/L$$

Because the selenium in fish tissue at these sites were measured as whole body concentrations, the whole body criterion of 8.5 µg/L is used, and an egg-ovary to whole body conversion factor is not required. As with the BAF approach, the lowest translated water criterion for all species is used as the site specific criterion. At site "San Joaquin R. at Durham Ferry State Recreation Area," the site specific criterion is based on the translated concentration for largemouth bass, and at the other 3 sites, the site specific criterion is based on the translated concentration for bluegill. Site specific water concentrations calculated using the mechanistic bioaccumulation modeling approach are more variable than concentrations calculated using the BAF approach, and range from 2.8 to 33.3 µg/L Table K-10). At all sites using both methods, the translated site specific water concentration criteria were higher than the measured water concentrations.

Table K-10. Site and species specific translated water concentrations using the mechanistic bioaccumulation modeling approach.

		Bluegill:			**Largemouth Bass:**		
Site	**EF (L/g)**	**WB Se (mg/kg)**	**TTF**	**Water SSC (µg/L)**	**WB Se (mg/kg)**	**TTF**	**Water SSC (µg/L)**
Mud Slough at Gun Club Road	1.37	5.70	0.59	10.61	6.85	0.49	12.65
Salt Slough at the San Luis National Wildlife Refuge	0.43	4.40	0.90	22.14	4.35	0.82	24.18
San Joaquin R. above Hills Ferry Road	0.36	3.00	0.96	24.79	2.30	0.71	33.31
San Joaquin R. at Durham Ferry State Recreation Area	0.75	1.95	2.30	4.95	1.75	4.03	2.83

3.3 Summary Comparison of the Mechanistic Bioaccumulation and BAF Approaches

A comparison of the mechanistic bioaccumulation and BAF approaches is included in Table K-11.

Table K-11. Comparison of mechanistic bioaccumulation and BAF approaches.

Mechanistic bioaccumulation modeling	**Bioaccumulation Factor (BAF)**
Knowledge of the aquatic system needed	No information on aquatic system needed
Choice of input parameters at discretion of state or tribe	No input parameters to choose
Species-specific	Species-specific
Can be applied at different sites if site *EF* can be estimated.	Site-specific
Fish tissue sampling not required for translation	Fish tissue and water sampling required