Chapter 5
Analysis

What's Covered in Chapter 5:

♦   Exposure Assessment

♦   Toxicity Assessment

The analysis phase of a risk assessment consists of assessing (1) exposure of a measurement receptor to a compound of potential concern (COPC), and (2) toxicity of a COPC to a measurement receptor. The exposure assessment (Section 5.1), and the toxicity assessment (Section 5.4) are used to characterize ecological risk, as discussed in Chapter 6.

5.1   EXPOSURE ASSESSMENT

Exposure is the contact (e.g., ingestion) of a receptor with a COPC. Exposure of ecological receptors to COPCs emitted from facility sources are evaluated through consideration of exposure pathways. All exposure pathways that are potentially complete should be evaluated. The existence of a potentially complete exposure pathway indicates the potential for a receptor to contact a COPC; it does not require that a receptor be adversely affected. Exposure pathways considered in this guidance include all direct uptake pathways of a COPC from media (e.g., soil, sediment, and surface water) for lower trophic level receptors evaluated at the community level, and ingestion of a COPC contaminated organism (plant or animal food item) or media for higher trophic level receptors evaluated as class-specific guilds. It should be noted that exposure pathways currently not addressed in this guidance due to the limitation of data include (1) inhalation and dermal exposure pathways for upper trophic level organisms, (2) ingestion via grooming and preening, and (3) foliar uptake of dissolved COPCs by aquatic plants.

Exposure assessment consists of quantifying exposure of a measurement receptor to a COPC. As previously noted (see Chapter 4), exposure to community and class-specific guild measurement receptors is assessed using different approaches. This is because the available toxicity reference values (*TRV*s) used in

risk characterization (see Chapter 6) for lower trophic level communities are media specific; whereas *TRV*s for upper trophic level class-specific guilds are provided in terms of dose ingested.

For community measurement receptors (e.g., water, sediment, and soil communities), the exposure assessment consists of determining the COPC concentration in the media that the particular community inhabits. For example, the COPC concentration in soil is determined during the exposure assessment for comparison to the NOAEL for terrestrial plants and soil invertebrates during risk characterization. For class-specific guild measurement receptors, exposure is assessed by quantifying the daily dose ingested of contaminated media and/or organism (expressed as the mass of COPC ingested per kilogram body weight per day). The following sections provide guidance on assessing exposure to community and class-specific guild measurement receptors.

5.2   Assessing Exposure to Community Measurement Receptors

Since exposure to communities is assumed to be primarily through contact with COPCs within the media they inhabit, the assessment of exposure for community measurement receptors is simply the determination of the COPC concentration in the media that they inhabit. Exposure for water, sediment, and soil community measurement receptors should be determined as follows:

> *Water Community -* Exposure to the water community as a measurement receptor (e.g., water invertebrates or phytoplankton in the freshwater/wetland food web) is assessed by determining the COPC dissolved water concentration (Cdw) (see Chapter 3 and Appendix B) at the specific location being evaluated (see Chapter 4).

> *Sediment Community -* Exposure to the sediment community as a measurement receptor (e.g., sediment invertebrates in the brackish/intermediate food web) is assessed by determining the COPC concentration in bed sediment ($Csed$) (see Chapter 3 and Appendix B) at the specific location being evaluated (see Chapter 4).

> *Soil Community -* Exposure to the soil community as a measurement receptor (e.g., soil invertebrates or terrestrial plants in the forest food web) is assessed by determining the COPC concentration in soil (Cs) (see Chapter 3 and Appendix B) at the specific location being evaluated (see Chapter 4).

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5.3   Assessing Exposure to Class-Specific Guild Measurement Receptors

Exposure to measurement receptors of class-specific guilds is assessed by quantifying the daily dose ingested of contaminated food items (i.e., plant and animal), and media. COPC daily dose ingested (expressed as the mass of COPC ingested per kilogram body weight per day) depends on the COPC concentration in plant and animal food items and media, the measurement receptor's trophic level (i.e., consumer), the trophic level of animal food items (i.e., prey), and the measurement receptor's ingestion rate of each food item and media. The complexity of the daily dose equation will depend on (1) the number of food items in a measurement receptor's diet, (2) the trophic level of each food item and of the measurement receptor. The daily dose of COPC ingested by a measurement receptor, considering all food items and media ingested, can be calculated from the following generic equation:

$$DD \ = \ \sum \ IR_F \cdot \ C_i \cdot \ P_i \cdot \ F_i \ + \ \sum \ IR_M \cdot \ C_M \cdot \ P_M \qquad\qquad \text{Equation 5-1}$$

where

DD	=	Daily dose of COPC ingested (mg COPC/kg BW-day)
IR_F	=	Measurement receptor plant or animal food item ingestion rate (kg/kg BW-day)
C_i	=	COPC concentration in ith plant or animal food item (mg COPC/kg)
P_i	=	Proportion of ith food item that is contaminated (unitless)
F_i	=	Fraction of diet consisting of plant or animal food item i (unitless)
IR_M	=	Measurement receptor media ingestion rate (kg/kg BW-day [soil or bed sediment] or L/kg BW-day [water])
C_M	=	COPC concentration in media (mg/kg [soil or bed sediment] or mg/L [water])
P_M	=	Proportion of ingested media that is contaminated (unitless)

Sections 5.3.1 through 5.3.2 (also see Appendix F) provide guidance for determining values for the above parameters; including (1) the determination of measurement receptor food item and media ingestion rates, and (2) the calculation of COPC concentrations in plant and animal food items. The use of *BCF*s and *FCM*s in calculating COPC concentrations in plant and animal food items is also discussed in the following sections. The daily dose should be computed using COPC media (i.e., soil, sediment, surface water, air) concentrations, at the location within the habitat supporting the food web being evaluated (see Chapter 4), for determination of (1) the COPC concentration in the plant or animal food item ingested, and (2) the

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COPC concentration in the media ingested. Guidance on the calculation of COPC concentrations in media being ingested is provided in Chapter 3 and Appendix B.

The daily dose of COPC ingested by a measurement receptor should be determined by summing the contributions from each contaminated plant, animal, and media food item. Equation 5-1 and consumer specific equations in Appendix F, are derived to account for 100 percent of the measurement receptor's diet (total daily mass of food items ingested) which can potentially be contaminated. However, if a food item or media at an actual site location is not contaminated (i.e., the COPC concentration in the media or resulting food item is zero), then the daily mass of that food item or media ingested does not contribute to the daily dose of COPC ingested. Also, Equation 5-1 does not directly include a term for home range, as defined spatially. However, the term accounting for the proportion of plant or animal food item that is contaminated, P_i, numerically accounts for the fraction of a respective food item that may potentially be obtained from outside the geographical limits of the impacted habitat (i.e., outside the area of contamination) being evaluated.

For measurement receptors ingesting more than one plant or animal food item, U.S. EPA OSW recommends that exposure be separately quantified assuming that the measurement receptor ingests both "equal" and "exclusive" diets. Not only does this constitute the most complete evaluation of exposure potential for a measurement receptor; if warranted, it also identifies which pathways are driving risk specific to a COPC and measurement receptor, and allows risk management efforts to be prioritized. Guidance for calculating *DD* assuming "equal diet" and "exclusive diet" is provided below.

> *Equal Diet* - To evaluate exposure to a measurement receptor based on an equal diet, the daily dose of COPC ingested is calculated assuming that the fraction of daily diet consumed by the measurement receptor is equal among food item groups. This is computed by setting the value for fraction of diet consisting of plant and/or animal food items, F_i, equal to 1.0 divided by the total number of plant and animal food item groups ingested. Therefore, F_i values within a specific *DD* equation would be the same numerically.

> *Exclusive Diet* - To evaluate exposure to a measurement receptor based on exclusive diets, the daily dose of COPC ingested is calculated assuming that the fraction of daily diet consumed by the measurement receptor is exclusively (100 percent) one food item group. This is computed by setting the value for F_i equal to 1.0 for each food item group at a time, while the F_i values for the remaining food item groups are set equal to zero. The food item designated as exclusive is alternated to each respective food item represented in the *DD* equation to obtain a numeric range of exposure values based on exclusive diets. If the daily diet of a food item (i.e., prey) of a measurement receptor (i.e., consumer) also consists of more than one plant or animal food item,

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then an equal diet should be assumed for the food item being consumed while evaluating exposure to the measurement receptor.

In addition to quantifying exposure based on equal and exclusive diets for measurement receptors, U.S. EPA OSW recommends that the following assumptions be applied in a screening level risk assessment.

- The COPC concentrations estimated to be in food items and media ingested are bioavailabile.

- Only contributions of COPCs from the sources (e.g., combustion stacks, fugitives) included in the risk assessment are considered in estimating COPC concentrations in food items and media.

- The measurement receptor's most sensitive life stage is present in the assessment area being evaluated in the risk assessment.

- The body weights and food ingestion rates for measurement receptors are conservative.

- Each individual species in a community or class-specific guild is equally exposed.

- The proportion of ingested food items and ingested media that is contaminated is assumed to be 100 percent (i.e., P_i is asigned a value of 1.0); which assumes that a measurement receptor feeds only in the assessment area.

Although conservative in nature, U.S. EPA OSW recommends use of these assumptions considering that the results of a screening level risk assessment are intended to support development of permits and focus risk management efforts. Site-specific exposure characterization that my warrant deviation from these screening level assumptions should be reviewed and approved by the appropriate permitting authority following recommendations provided in Section 3.12.

5.3.1   Ingestion Rates for Measurement Receptors

As indicated in Equation 5-1 above, species specific ingestion rates of food items and media, on a body weight basis, are required for calculating the daily dose of COPC ingested for each measurement receptor. As specified for use in the equations presented in Appendix F, it is important to ensure that food (i.e., plants and animals) and water ingestion rates are on a wet weight basis, and ingestion rates for soil and sediment are on a dry weight basis (see Appendix F). Table 5-1 provides values for ingestion rates for measurement receptors identified in the example food webs presented in Chapter 4. These values are primarily obtained from the allometric equations presented in the *Wildlife Exposure Factors Handbook*

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(U.S. EPA 1993o). Soil ingestion rates were calculated using the percent soil in estimated diets of wildlife as described in Beyer et al. (1994).

Species specific ingestion rates including food and water have been measured for few wildlife species. Therefore, allometric equations presented in the *Wildlife Exposure Factors Handbook* were used to calculate species specific food and media ingestion rates. Allometry is defined as the study of the relationship between the growth and size of one body part to the growth and size of the whole organism, including ingestion rates, and can be used to estimate species specific values for ingestion (U.S. EPA 1993o). Allometric equations should only be used for those taxonomic groups used to develop the allometric relationship. For example, equations developed for carnivorous mammals should not be used to calculate food ingestion rates for herbivorous mammals. For a detailed discussion on the development and limitations of the allometric equations used to obtain ingestion rate values presented in Table 5-1, see U.S. EPA (1993o) and Nagy (1987).

The use of individual species body weights may result in some uncertainty, since individual species usually exhibit values somewhat different from those predicted by allometric modeling derived using multiple species. However, this uncertainty is expected to be minimal since measurement receptors were selected to maximize exposure for each class-specific guild, as discussed in Section 4.4.2.

If species specific values are not available in U.S. EPA (1993o), or can not be represented by the allometric equations presented, other sources to evaluate include:

- U.S. Fish and Wildlife Service (FWS) publications (e.g., U.S. FWS 1979)

- State wildlife resource management agencies

- Published scientific literature

- Publications by wildlife conservation organizations (such as The National Audubon Society)

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TABLE 5-1

INGESTION RATES FOR EXAMPLE MEASUREMENT RECEPTORS

Measurement Receptor	Example Food Web[a]	Body Weight (kg)	Reference	Food IR [e] (kg WW/ kg BW-day)	Reference	Water IR (L /kg BW-day)	Reference	Soil/Sed IR [m] (kg DW/ kg BW-day)	Reference
American Kestrel	SG, TG, SS, FW, BR	1.00E-01	U.S. EPA 1993o	4.02E-01 [f]	U.S. EPA 1993o; Nagy 1987	1.25E-01 [k]	U.S. EPA 1993o	1.39E-03 [n]	Pascoe et al. 1996
American Robin	F	8.00E-02	U.S. EPA 1993o	4.44E-01 [f]	U.S. EPA 1993o; Nagy 1987	1.37E-01 [k]	U.S. EPA 1993o	1.43E-02 [o]	Beyer et al. 1994
Canvas Back	FW, BR, SW	7.70E-01 [b]	U.S. EPA 1993o	1.99E-01 [f]	U.S. EPA 1993o; Nagy 1987	6.43E-02 [k]	U.S. EPA 1993o	1.82E-03 [p]	Beyer et al. 1994
Deer Mouse	TG, F, SG, SS	1.48E-02	U.S. EPA 1993o	5.99E-01 [g]	U.S. EPA 1993o; Nagy 1987	1.51E-01 [l]	U.S. EPA 1993o	1.44E-03 [q]	Beyer et al. 1994
Least Shrew	SG, FW, TG	4.00E-03	National Audubon Society 1995	6.20E-01 [h]	U.S. EPA 1993o	1.72E-01 [l]	U.S. EPA 1993o	1.36E-02 [o]	Beyer et al. 1994
Long Tailed Weasel	TG ,F, SS	8.50E-02	National Audubon Society 1995	3.33E-01 [i]	U.S. EPA 1993o; Nagy 1987	1.27E-01 [l]	U.S. EPA 1993o	2.98E-03 [r]	Beyer et al. 1994
Mallard Duck	BR, FW	1.04E+00	U.S. EPA 1993o	1.79E-01 [f]	U.S. EPA 1993o; Nagy 1987	5.82E-02 [k]	U.S. EPA 1993o	3.18E-03	Beyer et al. 1994
Marsh Rice Rat	BR, SW	3.00E-02	National Audubon Society 1995	4.40E-01 [g]	U.S. EPA 1993o; Nagy 1987	1.41E-01 [l]	U.S. EPA 1993o	2.33E-03 [s]	Beyer et al. 1994
Marsh Wren	SW	1.00E-02	U.S. EPA 1993o	9.26E-01 [f]	U.S. EPA 1993o; Nagy 1987	2.75E-01 [k]	U.S. EPA 1993o	1.96E-02 [o]	Beyer et al. 1994
Mink	FW, BR	9.74E-01	U.S. EPA 1993o	2.16E-01 [i]	U.S. EPA 1993o; Nagy 1987	9.93E-02 [l]	U.S. EPA 1993o	1.93E-03 [r]	Beyer et al. 1994

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TABLE 5-1

INGESTION RATES FOR EXAMPLE MEASUREMENT RECEPTORS

Measurement Receptor	Example Food Web[a]	Body Weight (kg)	Reference	Food IR [e] (kg WW/ kg BW-day)	Reference	Water IR (L /kg BW- day)	Reference	Soil/Sed IR [m] (kg DW/ kg BW-day)	Reference
Mourning Dove	F, SS, TG, SG	1.50E-01 [c]	U.S. EPA 1993o	3.49E-01 [f]	U.S. EPA 1993o; Nagy 1987	1.09E-01 [k]	U.S. EPA 1993o	7.01E-03 [o]	Beyer et al. 1994
Muskrat	BR, FW	1.09E+00	U.S. EPA 1993o	2.67E-01 [j]	U.S. EPA 1993o; Nagy 1987	9.82E-02 [l]	U.S. EPA 1993o	6.41E-04	Beyer et al. 1994
Northern Bobwhite	SG, SS	1.50E-01	U.S. EPA 1993o	3.49E-01 [f]	U.S. EPA 1993o; Nagy 1987	1.09E-01 [k]	U.S. EPA 1993o	1.20E-02 [t]	Beyer et al. 1994
Northern Harrier	SW	9.60E-01	U.S. EPA 1993o	1.85E-01 [f]	U.S. EPA 1993o; Nagy 1987	5.99E-02 [k]	U.S. EPA 1993o	9.95E-03 [n]	Beyer et al. 1994
Red Fox	SW	3.94E+00	U.S. EPA 1993o	1.68E-01 [i]	U.S. EPA 1993o; Nagy 1987	8.63E-02 [l]	U.S. EPA 1993o	1.51E-03	Beyer et al. 1994
Red-tailed Hawk	F	9.60E-01 [d]	U.S. EPA 1993o	1.85E-01 [f]	U.S. EPA 1993o; Nagy 1987	5.99E-02 [k]	U.S. EPA 1993o	9.95E-03 [n]	Beyer et al. 1994
Salt-marsh Harvest Mouse	SW	9.10E-03	U.S. EPA 1993o	7.41E-01 [g]	U.S. EPA 1993o; Nagy 1987	1.58E-01 [l]	U.S. EPA 1993o	1.78E-03 [q]	Beyer et al. 1994
Short-tailed Shrew	F	1.50E-02	U.S. EPA 1993o	6.20E-01 [h]	U.S. EPA 1993o	1.51E-01 [l]	U.S. EPA 1993o	1.36E-02 [o]	Beyer et al. 1994
Spotted Sandpiper	SW, BR, FW	4.00E-02	U.S. EPA 1993o	5.69E-01 [f]	U.S. EPA 1993o; Nagy 1987	1.74E-01 [k]	U.S. EPA 1993o	4.15E-02 [u]	Beyer et al. 1994
Swift Fox	SG	1.40E+00	U.S. EPA 1993o	1.93E-01 [i]	U.S. EPA 1993o; Nagy 1987	9.34E-02 [l]	U.S. EPA 1993o	1.73E-03 [r]	Beyer et al. 1994
Western Meadow Lark	TG	9.00E-02	U.S. EPA 1993o	4.21E-01 [f]	U.S. EPA 1993o; Nagy 1987	1.31E-01 [k]	U.S. EPA 1993o	1.39E-02 [o]	Beyer et al. 1994

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TABLE 5-1

INGESTION RATES FOR EXAMPLE MEASUREMENT RECEPTORS

Measurement Receptor	Example Food Web[a]	Body Weight (kg)	Reference	Food IR [e] (kg WW/ kg BW-day)	Reference	Water IR (L /kg BW-day)	Reference	Soil/Sed IR [m] (kg DW/ kg BW-day)	Reference
White-footed Mouse	SS	1.00E-02	U.S. EPA 1993o	6.14E-01 [g]	U.S. EPA 1993o; Nagy 1987	1.52E-01 [l]	U.S. EPA 1993o	2.70E-03	Beyer et al. 1994

Notes: IR- Ingestion Rate; WW- Wet weight; DW-Dry Weight; BW- Body Weight; kg - kilogram; L - Liter

a = Food Webs: BR - Brackish/Intermediate Marsh; F - Forest; FW - Freshwater/Wetland; SG - Shortgrass Prairie; SS - Shrub/Scrub; SW - Saltwater Marsh; TG - Tallgrass Prairie.

b = The body weight reported for the mallard is used as a surrogate value for the canvas back.

c = The body weight reported for the northern bobwhite is used as a surrogate value for the morning dove.

d = The body weight reported for the red-tailed hawk is used as a surrogate value for the northern harrier.

e = Food ingestion rate (IR) values are reported in Table 5-1 as kg WW/kg BW-day. To convert IR from a dry weight (as calculated using allometric equations) to a wet weight basis, the following general equation is used:

$$\text{IR kg WW/kg BW-day} = (\text{IR kg DW/BW-day})/(1 - \%\ \text{moisture}/100)$$

Ingestion rate values provided in Table 5-1 are calculated based on assumed percent moisture content of food items of measurement receptors specified. For herbivores, the moisture content of ingested plant matter is assumed to be 88.0 percent (Taiz et al. 1991). For carnivores, the moisture content of ingested animal matter is assumed to be 68.0 percent (Sample et al. 1997). For omnivores, an equal fraction of plant and animal matter is assumed ingested with an overall average moisture content of 78.0 percent [(88.0 + 68.0)/2].

f = Food ingestion rates generated using the following allometric equation for all birds: IR $(g/day) = 0.648\ Wt^{0.651}$ (g).

g = Food ingestion rates generated using the following allometric equation for rodents: IR $(g/day) = 0.621\ Wt^{0.564}$ (g).

h = Allometric equations reported in U.S. EPA (1993o) do not represent intake rates for shrews; therefore, measured field values from the referenced sources are presented.

i = Food ingestion rates generated using the following allometric equation for all mammals: IR $(g/day) = 0.235\ Wt^{0.822}$ (g).

j = Food ingestion rates generated using the following allometric equation for herbivores: IR $(g/day) = 0.577\ Wt^{0.727}$ (g).

k = Water ingestion rates generated using the following allometric equation for all birds: IR $(L/day) = 0.059\ Wt^{0.670}$ (kg).

l = Water ingestion rates generated using the following allometric equation for all mammals: IR $(L/day) = 0.099\ Wt^{0.900}$ (kg).

m = Soil and sediment ingestion rates calculated based on percent soil in diet as reported in Beyer et al. 1994.

n = Percent soil in diet reported for the bald eagle is used as a surrogate value for the american kestrel, northern harrier, and red-tailed hawk.

o = Percent soil in diet is assumed as 10.0 percent of diet based on range presented in Beyer et al. 1994.

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p   =   Percent soil in diet reported for the mallard is used as a surrogate value for the canvas back.

q   =   Percent soil in diet reported for the white-footed mouse is used as a surrogate value for the deer mouse and salt-marsh harvest mouse.

r   =   Percent soil in diet reported for the red fox is used as a surrogate value for the long-tailed weasel, mink, and swift fox.

s   =   Percent soil in diet is assumed as 2.0 percent of diet based on range presented for herbivores.

t   =   Percent soil in diet reported for the wild turkey is used as a surrogate value for the northern bobwhite.

u   =   Percent soil in diet reported for the western sandpiper is used as a surrogate value for the spotted sandpiper.

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5.3.2   COPC Concentrations in Food Items of Measurement Receptors

Determination of COPC concentrations in food items is required for calculating the daily dose of COPC
ingested for each class-specific guild measurement receptor being evaluated. Since the risk assessment
considers potential future exposure that may occur as a result of facility emissions over time, these
concentrations are generally expected to be estimated mathmatically. The following subsections provide
guidance for estimating COPC concentrations in the following groups of food items:

- Invertebrates, phytoplankton, and rooted aquatic plants;

- Terrestrial plants;

- Fish; and

- Mammals, birds, reptiles, and amphibians.

5.3.2.1 COPC Concentration in Invertebrates, Phytoplankton, and Rooted Aquatic Plants

COPC concentrations in invertebrate, phytoplankton, and rooted aquatic plants can be calculated by
rearranging the mathmatical expression for a bioconcentration factor (*BCF*). Equation 5-2 is the
mathmatical definition of a *BCF*, which is the ratio, at steady-state, of the concentration of a compound in a
food item to its concentration in a media. Equation 5-3 is the same equation expressed in terms of a COPC
concentration in a food item.

$$BCF \;=\; \frac{C_i}{C_M} \qquad\qquad\text{Equation 5-2}$$

$$C_i \;=\; C_M \cdot BCF \qquad\qquad\text{Equation 5-3}$$

where
BCF = Bioconcentration factor (unitless [soil, sediment], or L/kg [water])
C_i = COPC concentration in *i*th plant or animal food item (mg COPC/kg)
C_M = COPC concentration in media (mg/kg [soil, sediment], or mg/L [water])

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Equation 5-3 estimates a COPC concentration in an invertebrate, phytoplankton, and rooted aquatic plant to evaluate dose ingested to the measurement receptor. Calculation of COPC concentrations in media is further discussed in Chapter 3 and Appendix B. Media-to-receptor *BCF*s are receptor- and media-specific, and values along with supporting discussion are provided in Appendix C. Appendix F provides specific equations and supporting discussion for calculating COPC concentrations in plant and animal food items.

Equilibrium Partitioning (EqP) Approach

When adequate site-specific characterization data is available, specifically organic carbon fraction data for soil and sediment, the permitting authority may elect in some cases to allow the calculation of COPC concentrations in soil invertebrate (Connell and Markwell 1990) or sediment invertebrate (U.S. EPA 1993q) using the equilibrium partitioning (EqP) approach. However, the EqP approach is not prefered over use of measured BCF values multiplied by the COPC concentration in the media (i.e., sediment or soil), following the approach previously discussed.

The EqP approach utilizes the correlation of the concentrations of nonionic organic compounds in sediment, on an organic carbon basis, to their concentrations in the interstitial water, to determine the observed biological effects on sediment invertebrate (U.S. EPA 1993q). The EqP approach is only applicable for (1) hydrophobic nonionic organic compounds, (2) soil- and sediment-invertebrates, and (3) COPCs with empirical water bioconcentration factors (U.S. EPA 1993q). Also, the EqP approach assumes that the partitioning of the compound in sediment organic carbon and interstitial water are in equilibrium, and the sediment—interstitial water equilibrium system provides the same exposure as a water-only exposure (U.S. EPA 1993q).

To calculate the COPC concentration in an invertebrate using the EqP approach, the soil or sediment interstitial water concentration should be multiplied by the *BCF* determined from a water exposure for a benthic invertebrate:

$$C_I = C_{IW} \cdot BCF_{WI}$$ Equation 5-4

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where

C_I	=	COPC concentration in soil or benthic invertebrate (mg/kg)
C_{IW}	=	COPC concentration in soil or sediment interstitial water (mg/L)
BCF_{WI}	=	Bioconcentration factor for water-to-invertebrate (L/kg)

Equation 5-5 is used to calculate the COPC concentration in soil or sediment interstitial water for this approach:

$$C_{IW} = \frac{C_M}{f_{oc} \cdot K_{oc}}$$

Equation 5-5

where

C_{IW}	=	COPC concentration in soil or sediment interstitial water (mg/L)
C_M	=	COPC concentration in media (mg/kg [soil, sediment])
f_{oc}	=	Fraction of organic carbon in soil or sediment (unitless)
K_{oc}	=	Organic carbon partitioning coefficient (L/kg)

5.3.2.2 COPC Concentration in Terrestrial Plants

The COPC concentration in terrestrial plants (C_{TP}) is calculated by summing the plant concentration due to direct deposition (Pd), air-to-plant transfer (Pv), and root uptake (Pr). Equation 5-6 should be used to compute a COPC concentration in terrestrial plants:

$$C_{TP} = Pd + Pv + Pr$$

Equation 5-6

where

C_{TP}	=	COPC concentration in terrestrial plants (mg COPC/kg WW)
Pd	=	COPC concentration in plant due to to direct deposition (mg/kg WW)
Pv	=	COPC concentration in plant due to air-to-plant transfer (mg/kg WW)
Pr	=	COPC concentration in plant due to root uptake (mg/kg WW)

Calculation of Pd, Pv, and Pr is presented in Chapter 3 and Appendix B. Calculation of C_{TP} is further discussed in Appendix F.

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5.3.2.3 COPC Concentration in Fish

The COPC concentration in fish is calculated by multiplying a COPC-specific *BCF* and trophic level-specific *FCM* by the dissolved water concentration, as follows:

$$C_F = BCF \cdot FCM \cdot C_{dw}$$ Equation 5-7

where
C_F	=	COPC concentration in fish (mg/kg)
BCF	=	Bioconcentration factor for water-to-fish (L/kg)
FCM	=	Food-chain multiplier (unitless)
C_{dw}	=	Dissolved phase water concentration (mg/L)

The COPC concentration in fish is calculated using dissolved phase water concentrations, since bioconcentration, or estimated bioaccumulation, values are typically derived from studies based on dissolved phase water concentrations. The *FCM* used to calculate a COPC concentration in fish should be appropriate for the trophic level of the fish ingested by a measurement receptor. Development of *FCM* values is discussed in the following subsection, and actual recommended values are provided in Table 5-2. The dissolved phase water concentration is calculated as discussed in Chapter 3 and Appendix B. Values for bioconcentration factors for water-to-fish, and discussion on their determination, can be found in Appendix C. Calculation of C_F is further discussed in Appendix F.

Food-Chain Multipliers

*FCM*s presented in Table 5-2 were adopted directly from U.S. EPA (1995k), which determined them for K_{ow} values ranging from 3.5 through 9.0 using the Gobas (1993) model. U.S. EPA determined *FCM*s to develop water criteria protective to wildlife of the Great Lakes (U.S. EPA 1995j). As presented in Equation 5-8, U.S. EPA (1995k) calculated trophic level specific *FCM*s (see Table 5-2) utilizing *BAF* values obtained from the Gobas (1993) model and compound specific K_{ow} values.

$$FCM = \frac{BAF_l}{K_{ow}}$$ Equation 5-8

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where

FCM	=	Food-chain multiplier (unitless)
BAF_l	=	Bioaccumulation factor reported on a lipid-normalized basis using the freely dissolved concentration of a chemical in the water (L/kg)
K_{ow}	=	Octanol-water partition coefficient (L/kg)

BAF values predicted using the Gobas (1993) model were based on chemical concentrations in both the water column and surface sediment. Bioaccumulation values for fish were determined from the rate of chemical uptake, the rate of chemical depuration (including excretion), metabolism, and dilution due to growth. As reported in U.S.. EPA (1995k), data on physicochemical parameters and species characteristics reported by Oliver and Niimi (1988), Flint (1986), and Gobas (1993) were used.

For each K_{ow} value, the Gobas (1993) model reported correlating BAF_l values specific to each organism in the food web. U.S. EPA (1995k) determined trophic level-specific *FCM*s by calculating the geometric mean of the *FCM* for each organism in each respective trophic level. The *FCM*s were developed assuming no metabolism of a compound. Thus, for compounds where metabolism may occur (i.e., some PAHs), the COPC concentration in fish ingested by a measurement receptor may be overestimated. This information should be noted as an uncertainty in risk characterization. It should also be noted that the *FCM* values presented in Table 5-2 were developed using K_{ow} values reported in U.S. EPA (1995k); which may differ from K_{ow} values specified in Appendix A-2 of this guidance.

Using the U.S. EPA (1995k) assumption that a compound's log K_{ow} value approximates its BCF_l, Equation 5-8 for determining *FCM* values can also be expressed as follows:

$$FCM = \frac{BAF_l}{BCF_l} \qquad\qquad \text{Equation 5-9}$$

where

FCM	=	Food-chain multiplier (unitless)
BAF_l	=	Bioaccumulation factor reported on a lipid-normalized basis using the freely dissolved concentration of a chemical in the water (L/kg)
BCF_l	=	Bioconcentration factor reported on a lipid-normalized basis using the freely dissolved concentration of a chemical in the water (L/kg)

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Equation 5-9 can also be written to demonstrate the relation of a *BCF* multiplied by a *FCM* to estimate a *BAF*, as shown in the following equation:

$$BAF = BCF \cdot FCM$$ Equation 5-10

where

BAF	=	Bioaccumulation factor (L/kg)
BCF	=	Bioconcentration factor (L/kg)
FCM	=	Trophic level-specific food-chain multiplier (unitless)

*FCM*s are specified for use in this guidance to model a COPC concentration in fish, and also mammalian and bird food items, that are ingested by a measurement receptor. The *BCF-FCM* approach accounts for the uptake or bioaccumulation of COPCs into organisms, typically represented in equations as a *BAF* (U.S. EPA 1995j). The availability of data allows the *BCF-FCM* approach to be more consistently applied across class-specific guilds within food webs being evaluated.

U.S. EPA OSW recognizes the limitations and uncertainties of applying *FCM*s derived from aquatic food web data to terrestrial receptors, as well as all top level consumers, whether their food is chiefly aquatic or not. However, the *BCF-FCM* approach is recommended in this guidance because (1) evaluation of multiple food chain exposure pathways is typically required to estimate risk to multiple mammalian and avian guilds in several food webs, (2) screening level risk assessment results are intended to support develoment of permits and focus risk management efforts, rather than as a final point of departure for further evaluation, and (3) U.S. EPA OSW is aware of no other applicable multipathway approaches for consistently and reproducibly estimating COPC concentrations in prey ingested by upper-trophic-level ecological receptors, considering current data limitations. Therefore, U.S. EPA OSW believes the *BCF-FCM* approach is the best available quantitative method for estimating COPC concentrations in upper trophic level food items ingested by measurement receptors, considering data availabilty and the objectives inherent to a screening level risk assessment.

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TABLE 5-2

FOOD-CHAIN MULTIPLIERS

Log K_{ow}	Trophic Level of Consumer		
	2	**3**	**4**
2.0	1.0	1.0	1.0
2.5	1.0	1.0	1.0
3.0	1.0	1.0	1.0
3.1	1.0	1.0	1.0
3.2	1.0	1.0	1.0
3.3	1.0	1.1	1.0
3.4	1.0	1.1	1.0
3.5	1.0	1.1	1.0
3.6	1.0	1.1	1.0
3.7	1.0	1.1	1.0
3.8	1.0	1.2	1.0
3.9	1.0	1.2	1.1
4.0	1.0	1.3	1.1
4.1	1.0	1.3	1.1
4.2	1.0	1.4	1.1
4.3	1.0	1.5	12
4.4	1.0	1.6	1.2
4.5	1.0	1.8	1.3
4.6	1.0	2.0	1.5
4.7	1.0	2.2	1.6
4.8	1.0	2.5	1.9
4.9	1.0	2.8	2.2
5.0	1.0	3.2	2.6
5.1	1.0	3.6	3.2
5.2	1.0	4.2	3.9
5.3	1.0	4.8	4.7
5.4	1.0	5.5	5.8
5.5	1.0	6.3	7.1
5.6	1.0	7.1	8.6

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TABLE 5-2

FOOD-CHAIN MULTIPLIERS

Log K_{ow}	Trophic Level of Consumer		
	2	**3**	**4**
5.7	1.0	8.0	10
5.8	1.0	8.8	12
5.9	1.0	9.7	14
6.0	1.0	11	16
6.1	1.0	11	18
6.2	1.0	12	20
6.3	1.0	13	22
6.4	1.0	13	23
6.5	1.0	14	25
6.6	1.0	14	26
6.7	1.0	14	26
6.8	1.0	14	27
6.9	1.0	14	27
7.0	1.0	14	26
7.1	1.0	14	25
7.2	1.0	14	24
7.3	1.0	13	23
7.4	1.0	13	21
7.5	1.0	13	19
7.6	1.0	12	17
7.7	1.0	11	14
7.8	1.0	10	12
7.9	1.0	9.2	9.8
8.0	1.0	8.2	7.8
8.1	1.0	7.3	6.0
8.2	1.0	6.4	4.5
8.3	1.0	5.5	3.3
8.4	1.0	4.7	2.4
8.5	1.0	3.9	1.7
8.6	1.0	3.3	1.1

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TABLE 5-2

FOOD-CHAIN MULTIPLIERS

Log K_{ow}	Trophic Level of Consumer		
	2	**3**	**4**
8.7	1.0	2.7	0.78
8.8	1.0	2.2	0.52
8.9	1.0	1.8	0.35
9.0	1.0	1.5	0.23

Source: U.S. EPA. 1995k. "Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation factors." EPA-820-B-95-005. Office of Water. Washington, D.C. March.
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5.3.2.4 COPC Concentration in Mammals, Birds, Amphibians, and Reptiles

The COPC concentration in mammals and birds, as food items ingested by measurement receptors, are estimated using equations specific to each guild (i.e., herbivores, omnivores, and carnivores), and based on the plant and animal food items, and media ingested. Similar to calculating the COPC concentration in fish, a *BCF-FCM* approach is used to account for bioaccumulation. However, the contribution of COPC concentrations from each food item ingested must be accounted for directly for wildlife, whereas, the derivation of *BCF-FCM* values already accounts for the COPC contributions from all pathways for fish. Also for wildlife, a ratio of *FCM*s is applied to each animal food item ingested to account for the increase in COPC concentration occurring between the trophic level of the prey item (TLn) and the trophic level of the omnivore (TL3) or carnivore (TL4).

General equations for estimating COPC concentrations of food items in each guild, including use of a *FCM* ratio to estimate biomagnification, are described in the following subsections using mammals and birds as examples. Specific equations and discussion of associated parameters are provided in Appendix F. It should be noted that due to limited availabilty of biotransfer and toxicity data for reptiles and amphibians, the equations in the following subsections and in Appendix F have not been specifically described for use to model exposure to these receptors. However, if site-specific conditions and data warrant evaluation of reptiles and amphibians, the permitting authority may elect to utilize the same generic equations presented.

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Herbivorous Mammals and Birds

As indicated in Equation 5-11, the COPC concentration in herbivorous mammals and birds is calculated by summing the contribution due to ingestion of contaminated plant food items and media. The general equation for computing COPC concentration in herbivores is as follows:

$$C_H = \sum (C_{Pi} \cdot BCF_{Pi\text{-}H} \cdot P_{Pi} \cdot F_{Pi}) + (C_{s/sed} \cdot BCF_{S/BS\text{-}H} \cdot P_{S/BS})$$
$$+ (C_{wctot} \cdot BCF_{W\text{-}H} \cdot P_W)$$

Equation 5-11

where

C_H	=	COPC concentration in herbivore (mg/kg)
C_{Pi}	=	COPC concentration in ith plant food item (mg/kg)
$BCF_{Pi\text{-}H}$	=	Bioconcentration factor for plant-to-herbivore for ith plant food item (unitless)
P_{Pi}	=	Proportion of ith plant food item in diet that is contaminated (unitless)
F_{Pi}	=	Fraction of diet consisting of ith plant food item (unitless)
$C_{s/sed}$	=	COPC concentration in soil or bed sediment (mg/kg)
$BCF_{S/BS\text{-}H}$	=	Bioconcentration factor for soil-to-plant or bed sediment-to-plant (unitless)
$P_{S/BS}$	=	Proportion of soil or bed sediment in diet that is contaminated (unitless)
C_{wctot}	=	Total COPC concentration in water column (mg/L)
$BCF_{W\text{-}HM}$	=	Bioconcentration factor for water-to-herbivore (L/kg)
P_W	=	Proportion of water in diet that is contaminated (unitless)

Media-to-herbivore *BCF* values are COPC and receptor-specific and provided in Appendix C. As discussed in Appendix D, plant-to-herbivore *BCF* values are receptor-specific and determined from biotransfer factors. Calculation of COPC concentrations in plant food items and media is further discussed in previous sections of Chapter 5, and in Chapter 3 and Appendix B. The variables representing the diet fraction and proportion of diet contaminated are discussed in Section 5.3 and Appendix F. Appendix F also provides specific equations and supporting discussion for calculating the COPC concentration in herbivores.

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Omnivorous Mammals and Birds

As indicated in Equation 5-12, the COPC concentration in omnivorous mammals and birds is calculated by summing the contribution due to ingestion of contaminated animal and plant food items, and media. However, unlike herbivores which are TL2 consumers, omnivores are TL3 consumers of animal food items and a ratio of FCMs is applied to each animal food item ingested to account for the increase in COPC concentration occurring between the trophic level of the prey item (TLn) and the trophic level of the omnivore (TL3). In general, the COPC concentration in omnivores depends on the COPC concentration in each food item ingested, and the trophic level of each food item, as follows:

$$C_{OM} = \sum \left(C_{Ai} \cdot \frac{FCM_{TL3}}{FCM_{TLn-Ai}} \cdot P_{Ai} \cdot F_{Ai} \right) + \sum \left(C_{Pi} \cdot BCF_{Pi-OM} \cdot P_{Pi} \cdot F_{Pi} \right)$$

Equation 5-12

$$+ \left(C_{s/sed} \cdot BCF_{S/BS-OM} \cdot P_{S/BS} \right) + \left(C_{wctot} \cdot BCF_{W-OM} \cdot P_W \right)$$

where

C_{OM}	=	COPC concentration in omnivore (mg/kg)
C_{Ai}	=	COPC concentration in ith animal food item (mg/kg)
FCM_{TL3} =		Food chain multiplier for trophic level 3 (unitless)
FCM_{TLn-Ai}	=	Food chain multiplier for trophic level of ith animal food item (unitless)
P_{Ai}	=	Proportion of ith animal food item in diet that is contaminated (unitless)
F_{Ai}	=	Fraction of diet consiting of ith animal food item (unitless)
BCF_{Pi-OM}	=	Bioconcentration factor for plant-to-omnivore for ith plant food item (unitless)
C_{Pi}	=	COPC concentration in ith plant food item (mg/kg)
P_{Pi}	=	Proportion of ith plant food item that is contaminated (unitless)
F_{Pi}	=	Fraction of diet consiting of ith plant food item (unitless)
$C_{s/sed}$	=	COPC concentration in soil or bed sediment (mg/kg)
$BCF_{S/BS-OM}$	=	Bioconcentration factor for soil- or bed sediment-to-omnivore (unitless)
$P_{S/BS}$	=	Proportion of soil or bed sediment in diet that is contaminated (mg/kg)
C_{wctot}	=	Total COPC concentration in water column (mg/L)
BCF_{W-OM}	=	Bioconcentration factor for water-to-omnivore (L/kg)
P_W	=	Proportion of water in diet that is contaminated (unitless)

Media-to-omnivore BCF values are COPC and receptor-specific and provided in Appendix C. The use of an FCM ratio to estimate biomagnification between trophic levels is discussed in a following subsection.

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Calculation of COPC concentrations in animal food items is further discussed in previous sections of Chapter 5. Calculation of COPC concentrations in plant food items and media is further discussed in previous sections of Chapter 5, and in Chapter 3 and Appendix B. The variables representing the diet fraction and proportion of diet contaminated are discussed in Section 5.3 and Appendix F. Appendix F also provides specific equations and supporting discussion for calculating the COPC concentration in omnivores.

Carnivorous Mammals and Birds

As indicated in Equation 5-13, the COPC concentration in carnivorous mammals and birds is calculated by summing the contribution due to ingestion of contaminated animal and media food items. In general, the equation for computing a COPC concentration for carnivorous food items is similar to the corresponding equation for omnivores; only without the component accounting for ingestion of plant food items. Similarly, a ratio of *FCM*s is applied to each animal food item ingested to account for the increase in COPC concentration occurring between the trophic level of the prey item (TLn) and the trophic level of the carnivore (TL4). The COPC concentration in carnivores depends on the COPC concentration in media, in each animal food item ingested, their respective trophic level, as follows:

$$C_C = \sum (C_{Ai} \cdot \frac{FCM_{TL4}}{FCM_{TLn-Ai}} \cdot P_{Ai} \cdot F_{Ai}) + (C_{s/sed} \cdot BCF_{S/BS-C} \cdot P_{S/BS})$$

$$+ (C_{wctot} \cdot BCF_{W-C} \cdot P_W)$$

Equation 5-13

where

C_C	=	COPC concentration in carnivore (mg/kg)
C_{Ai}	=	COPC concentration in *i*th animal food item (mg/kg)
$FCM_{TL3}=$		Food chain multiplier for trophic level 4 (unitless)
FCM_{TLn-Ai}	=	Food chain multiplier for trophic level of *i*th animal food item (unitless)
P_{Ai}	=	Proportion of *i*th animal food item in diet that is contaminated (unitless)
F_{Ai}	=	Fraction of diet consisting of *i*th animal food item (unitless)
$C_{s/sed}$	=	COPC concentration in soil or bed sediment (mg/kg)
$BCF_{S/BS-C}$	=	Bioconcentration factor for soil- or bed sediment-to-carnivore (unitless)

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$P_{S/BS}$	=	Proportion of soil or bed sediment in diet that is contaminated (mg/kg)
C_{wctot}	=	Total COPC concentration in water column (mg/L)
$BCF_{W\text{-}C}$	=	Bioconcentration factor for water-to-carnivore (L/kg)
P_W	=	Proportion of water in diet that is contaminated (unitless)

Media-to-carnivore *BCF* values are COPC and receptor-specific and provided in Appendix C. The use of an *FCM* ratio to estimate biomagnification between trophic levels is discussed in the following subsection. Calculation of COPC concentrations in animal food items is further discussed in previous sections of Chapter 5. Calculation of COPC concentrations in plant food items and media is further discussed in previous sections of Chapter 5, and in Chapter 3 and Appendix B. The variables representing the diet fraction and proportion of diet contaminated are discussed in Section 5.3 and Appendix F. Appendix F also provides specific equations and supporting discussion for calculating the COPC concentration in carnivores.

Use of Food Chain Multiplier Ratio to Estimate Biomagnification

Biomagnification involves the transfer of a chemical in food through successive trophic levels (Hamelink et al. 1971). Chemicals with greatest potential to biomagnify are highly lipophillic, have low water solubilities, and are resistant to being metabolized (Metcalf et al. 1975). To account for COPC biomagnification in the food chain, U.S. EPA OSW recommends the use of *FCM* ratios as derived by U.S. EPA (1995k).

FCM ratios are used to estimate the increase in a COPC concentration resulting from the ingestion of TL2 prey (i.e., animal food item) by a TL3 measurement receptor (i.e., omnivore or carnivore), and the ingestion of TL2 and TL3 prey by a TL4 measurement receptor. Biomagnification, expressed as a biomagnification factor (*BMF*), equals the quotient of the *FCM* of the measurement receptor divided by the *FCM* of the prey. It is important to note that the basic difference between the *FCM* and *BMF* is that the *FCM*s relate back to trophic level one, whereas *BMF*s always relate back to the preceding trophic level (U.S. EPA 1995k). This relation is entirely compatible, but confusion can result if the terms specific to trophic level are not used consistently and clearly (U.S. EPA 1995k). As presented in U.S. EPA (1995k), the following relation of *FCM* to *BMF* can be expressed as follows:

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$$BMF_{TL2} = FCM_{TL2} \qquad\qquad \text{Equation 5-14}$$

$$BMF_{TL3} = FCM_{TL3}/FCM_{TL2} \qquad\qquad \text{Equation 5-14A}$$

where

BMF_n =   Biomagnification factor for nth trophic level
FCM_{TLn} =   Food chain multiplier for nth trophic level

5.4   ASSESSMENT OF TOXICITY

Toxicity of a COPC is assessed by identifying toxicity reference values (*TRV*s) specific to a COPC and the measurement receptor being evaluated. As discussed in Chapter 6, *TRV*s are subsequently set as the denominator for computing COPC ecological screening quotients (*ESQ*s) during risk characterization. The available *TRV*s used in risk characterization for lower trophic level communities are media specific; whereas *TRV*s for upper trophic level class-specific guilds are provided in terms of dose ingested. *TRV*s for community and class-specific guild measurement receptors are further described below:

- Community (lower trophic level) *TRV*s are media specific and used to screen ecological effects to receptors inhabiting soil, surface water, and sediment. Community *TRV*s are expressed on a concentration basis, such as milligrams of COPC per kilogram of soil, and generally either:

  (1)   a COPC media concentration that, based on its intended use by a regulatory agency, confers a high degree or protection to receptor populations or communities inhabiting the media (these include regulatory values such as federal ambient water quality criteria, state no-effect-level sediment quality guidelines, and sediment screening effect concenentrations), or

  (2)   a laboratory-derived toxicity value representing a COPC media concentration that causes, over a chronic exposure duration, no adverse effects to a representative ecological receptor (e.g., no-observed-effect-concentration).

- Class-specific guild (upper trophic level) *TRV*s are used to screen ecological effects to wildlife, and expressed as a COPC daily dose ingested that causes, over a chronic exposure duration, no observed adverse effects to a measurement receptor. Class-specific guild *TRV*s are expressed in units of mass (e.g., milligrams or micrograms) of COPC per

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kilogram body weight (wet weight) per day.

Guidance for selection of *TRV*s for community and class-specific guild measurement receptors is provided in the following sections. *TRV*s specific to example measurement receptors presented in the food webs in Chapter 4 are available in Appendix E.

5.4.1   General Guidance on Selection of Toxicity Reference Values

Compound specific *TRV*s should be identified for each measurement receptor evaluated to characterize risk to a community or class-specific guild. U.S. EPA OSW recommends evaluation of the following sources of toxicity values, listed in order of general preference, in determining *TRV*s for use in a screening level risk assessment:

> ***Toxicity values developed and/or adopted by federal and/or state regulatory agencies; generally provided in the form of standards, criteria, guidance, or benchmarks.*** Toxicity values developed and/or adopted by federal or state regulatory agencies are generally media specific, and reported only for surface water and sediment. Examples include state or federal ambient water quality criteria (AWQC), National Oceanic and Atmospheric Administration (NOAA) effects range-low (ERL) values for sediment (Long et al. 1995), and State of Florida sediment quality guidelines (MacDonald 1993).

> ***Toxicity values published in scientific literature.*** Appropriate values should be derived from a laboratory study which characterizes adverse effects on ecologically-relevant endpoints (e.g., growth, reproduction, mortality). As discussed in Section 5.4.1.3, toxicity values obtained from scientific literature may also require application of an uncertainty factor (UF) to account for extrapolation uncertainty.

> ***Toxicity values calculated for sediment using equilibrium partitioning (EqP) approach.*** The EqP approach is further described in Section 5.3.2.1. Calculating sediment toxicity values using the EqP approach requires determination of (1) an organic carbon content of the sediments, and (2) a corresponding surface water toxicity value.

> ***Toxicity values from surrogate compounds.*** Surrogate compounds are selected through evaluation of parameters such as chemical structure and toxicity mechanisms of action. For example, low molecular weight (i.e. those have two or less rings) polyaromatic hydrocarbons (PAH's) could be grouped together and evaluated using the toxicity data from a PAH congener belonging to this group.

The evaluation of toxicity values published in scientific literature should consider (1) ecological relevance of the study, (2) exposure duration (e.g., chronic, acute), and (3) study endpoints (e.g., NOAEL, LOAEL). The identification of literature toxicity values used to derive *TRV*s should focus on toxicological data

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characterizing adverse effects on ecologically relevant endpoints, such as growth, seed germination, reproduction, and survival. Study endpoints specified for reported toxicity values generally include the following:

- Soil, surface water, and sediment measurement receptors

    - No-observed-effect-level (NOEL) or no-observed-effect-concentration (NOEC)
    - Lowest-observed-effect-level (LOEL) or lowest-observed-effect-concentration (LOEC)
    - Median lethal concentration to 50 percent of the test population (LC50) or median effective concentration for 50 percent of the test population (EC50)

- Wildlife measurement receptors

    - No-observed-adverse-effect-level (NOAEL)
    - Lowest-observed-adverse-effect-level (LOAEL)
    - Median lethal dose to 50 percent of the test population (LD50)

Evaluation of toxicity test data is further discussed in Section 5.4.1.1.

When multiple studies are assessed equally under the criteria above, professional judgement can be applied to determine the most appropriate study and corresponding toxicity value to be selected as the *TRV* (see Section 5.4.1.2). As discussed in Section 5.4.1.3, toxicity values obtained from scientific literature may also require application of an UF to account for extrapolation uncertainty (due to differences in test endpoint and exposure duration) when considering use of the test value as a *TRV* in a screening level risk assessment.

5.4.1.1 Evaluation of Toxicity Test Data

A *TRV* should represent a COPC concentration or dose that causes no observed adverse effects to an ecologically relevant endpoint of a receptor exposed for a chronic (long-term) duration. As noted above, evaluation of test data from ecologically relevant studies should be further assessed based on exposure duration and study endpoint.

The following hierarchy, in terms of decreasing preference, should be followed to assess exposure duration and study endpoint:

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1.   Chronic NOAEL

2.   Subchronic NOAEL

3.   Chronic LOAEL

4.   Subchronic LOAEL

5.   Acute median lethality point estimate

6.   Single dose toxicity value

The following guidelines should be used to generally determine exposure duration:

- For fish, mammals, and birds:

  - A chronic test lasts for more than 90 days

  - A subchronic test lasts from 14 to 90 days

  - An acute test lasts less than 14 days

- For other receptors:

  - A chronic test lasts for 7 or more days
  - A subchronic test lasts from 3 to 6 days
  - An acute test lasts less than 3 days

The logic followed to identify the a toxicity value should be fully documented. Sources of toxicity values include electronic databases, reference compendia, and technical literature. Toxicity values identified from secondary sources should be verified, wherever possible, by reviewing the original study. If an original study is unavailable, or multiple studies of similar quality are available, best professional judgment should be used to determine an appropriate toxicity value.

5.4.1.2 Best Professional Judgement for Evaluating Toxicity Values

If more than one toxicity study meets a set of qualifying criteria applicable for study endpoint and exposure duration, best professional judgement should be used to identify the most appropriate study and corresponding toxicity value for *TRV* selection. The most appropriate study is the one with the least uncertainty about the accuracy of the value of endpoint (i.e., NOAEL) that, ultimately, provides the greatest degree of protectiveness to the applicable measurement receptor. The most appropriate study

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should be identified by reviewing the experimental design of each study. Discussed below are important

aspects of experimental design that should be evaluated.

- *Number of treatments, spread between treatments, and number of replicates per treatment.* The number of treatments and the spread between exposure concentrations (or dose groups) will affect the accuracy of the test endpoint (such as the NOAEL). That is, the smaller the spread between the NOAEL and LOAEL, the less the uncertainty is about the true concentration or dose at which there is no adverse effect. The statistical power of a toxicity test (or any test for that matter) is dependent, in large part, on the number of replicates (or number of animals per dose). That is, the ability of a test to detect statistical differences (test sensitivity) increases as the number of replicates increase.

- *Exposure route.* The exposure route of the test should coincide with the applicable exposure route or pathway under consideration in the risk assessment. For example, the screening level risk assessment may evaluate the risk of contaminated soils to terrestrial plants due to exposure to bulk soil. Therefore, a terrestrial plant toxicity study that evaluated the effects of soil solutions on a plant species may be a less appropriate than a study based on effects of bulk soil.

- *Exposure during sensitive life stage.* Ideally, all toxicity studies would evaluate the effects of a toxicant on the most sensitive life stage, such as neonatal zooplankton and first instar larvae. Therefore, the exposure duration should be receptor- and toxicant-specific.

- *Nominal or measured test concentrations*. Measured test concentrations more accurately estimate the true concentration of a toxicant presented to a receptor. Nominal, or unmeasured, test concentrations do not account for potential losses of the toxicant (such as toxicant adsorbed to particulate material) or for inaccuracies in preparing test solutions. In addition, samples for measuring test concentrations should be collected from the exposure chamber, not the delivery system.

- *Use, type, and performance of controls.* A positive control (no toxicant) should be used in each toxicity study. The only difference between a positive control and a treatment is the absence of the toxicant from the control. Performance in a positive control should meet pre-existing performance criteria (such as acceptable survival). Treatment performance should be statistically compared to (or inferred from in some circumstances) to control performance to identify statistical endpoints (such as the NOAEL and LOAEL). In some situations, a negative control (toxicant with known toxicity, also called a performance control) may be appropriate. If a negative control is used, its results should be compared to standards to determine if test receptor sensitivity was acceptable.

- *Method used to determine endpoint (i.e., NOAEL).* Ideally, an acceptable number of replicates should be used so a test has statistical power. An appropriate statistical test should be performed to identify the NOAEL. In some cases, the NOAEL may have to be inferred because of insufficient number of replicates. While the latter is not unscientific, the former method provides a measure that the conclusion might be false. For example, if test results are statistically analyzed at a probability level of 95 percent, there is a 5 percent chance that the results of the statistical analysis are false.

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5.4.1.3 Uncertainty Factors for Extrapolation From Toxicity Test Values to *TRV*s

Incomplete knowledge of the actual toxicity of a chemical leads to the use of UFs to reduce the likelihood that risk estimates do not underestimate risk. Historically, UFs have been used for various extrapolations, and their applications reflect policy to provide conservative estimates of risk (Chapman et al. 1998). As discussed below, UFs are used in the risk assessment to reduce the probability of underestimating ecological risk from exposures to combustor emissions. This is performed by multiplying a toxicity value by a UF to produce a *TRV* reflecting an NOAEL for a chronic exposure duration.

UFs should be used to convert a toxicity value to a chronic NOAEL-based *TRV*. In most cases, the UFs discussed below should be applicable to available toxicity values. In some cases, however, irregular toxicity data (such as, a subchronic LC50) may be the only available information. In these cases, the toxicity data should be thoroughly reviewed and professional judgment should be used to identify appropriate UFs that are consistent with those listed below. Special attention should be taken with toxicity values from single oral dose, intraperitoneal, and subchronic lethality tests.

Specifically, UFs should be used to account for extrapolation uncertainty due to differences in test endpoint and exposure duration:

- Test endpoint uncertainty—extrapolation from a non-NOAEL endpoint (e.g., LOAEL, LD50) to an NOAEL endpoint

- Duration uncertainty—extrapolation from a single dose, acute, or subchronic duration to a chronic duration

Except as noted above for irregular toxicity data, the following UFs (Calabrese and Baldwin 1993) should be used to convert a toxicity test endpoint to a *TRV* equivalent to a chronic NOAEL:

- A chronic LOAEL (or LOEL or LOEC) should be multiplied by a UF of 0.1 to convert it to a chronic NOAEL

- A subchronic NOAEL should be multiplied by a UF of 0.1 to convert it to a chronic NOAEL.

- An acute lethal value (such as an LC50 or LD50) should be multiplied by an UF of 0.01 to convert it to a chronic NOAEL.

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