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4. EXPOSURE ESTIMATES

This section provides equations to estimate oral doses of chemical contaminants for wildlife, along with a discussion of dose estimates for other exposure routes. Section 4.1 provides general dose equations. Equations for drinking water exposures are presented in Section 4.1.1, followed by equations for dietary exposures in Section 4.1.2. In the dietary exposure section, data on the caloric and water content of various food types and diet assimilation efficiencies are also provided. An equation and data to facilitate estimating doses received through soil or sediment ingestion are discussed in Section 4.1.3. Sections 4.1.4 and 4.1.5 provide a qualitative discussion of inhalation and dermal dose estimates. Section 4.2 describes considerations for analyses of uncertainty in exposure assessments. References are provided in Section 4.3.

4.1. GENERAL DOSE EQUATIONS

EPA's (1992a) *Framework for Ecological Risk Assessment* defines exposure as the co-occurrence of or contact between a stressor and an ecological component. When assessing risks of exposure to chemical contaminants, potential dose is often the metric used to quantify exposure. Potential dose is defined as the amount of chemical present in food or water ingested, air inhaled, or material applied to the skin (U.S. EPA, 1992b). Potential dose is analogous to the administered dose in a toxicity test. Because exposure to chemicals in the environment is generally inadvertent, rather than administered, EPA's (1992b) *Guidelines for Exposure Assessment* use the term potential dose rather than administered dose.

A general equation for estimating dose for intake processes is:

$$D_{pot} = \int_{t1}^{t2} C(t)\ IR(t)\ dt \qquad [4\text{-}1]$$

where D_{pot} is the total potential dose over time (e.g., total mg contaminant intake between t1 and t2), C(t) is the contaminant concentration in the contacted medium at time t (e.g., mg contaminant/kg medium), and IR(t) is the intake rate of the contaminated medium at time t measured as mass ingested or inhaled by an animal per unit time (e.g., kg medium/day). If C and IR are constant over time, then the total potential dose can be estimated as:

$$D_{pot} = C \times IR \times ED \qquad [4\text{-}2]$$

where ED is the exposure duration and equals t2 - t1.

Therefore, if C and IR are constant, the potential average daily dose (ADD_{pot}) for the duration of the exposure, normalized to the animal's body weight (e.g., mg/kg-day), is estimated by dividing total potential dose by ED and by body weight (BW):

$$ADD_{pot} = (C \times IR \times ED) / (BW \times ED), \text{ or} \qquad [4\text{-}3]$$
$$ADD_{pot} = (C \times IR) / BW$$

If C or IR vary over time, they may be averaged over ED. However, it is not always appropriate to average intake over the entire exposure duration: For example, a given quantity of a chemical might acutely poison an animal if ingested in a single event, but if that amount is averaged over a longer period, effects might not be expected at all. Similarly, developmental effects occur only during specific periods of gestation or development. A toxicologist should be consulted to determine which effects may be of concern given the exposure pattern and chemicals of interest. For carcinogenic compounds, it may be more appropriate to average exposure over the animal's lifetime. Again, address any questions to a toxicologist.

In addition, IR and BW can be combined into a normalized ingestion or inhalation rate (NIR) (e.g., kg medium/kg body weight - day):

$$NIR = IR / BW \qquad [4\text{-}4]$$

Therefore,

$$ADD_{pot} = C \times NIR \qquad [4\text{-}5]$$

It is important to remember that NIR can vary with changes in age, size, and reproductive status of an animal.

Two other variables often are used in calculations of average daily dose. A frequency term (FR) is used to denote the fraction of the time that an animal is exposed to contaminated media. In ecological exposure assessments, this term often is used when the foraging range of an animal is larger than the area of contamination.[a] An absorption factor (ABS) is used when an estimate of absorbed dose rather than potential dose is desired. It is commonly assumed that absorption in the species of concern in the field is the same as in the test organism, so no absorption factor is needed. However, if absorption is expected to differ, a ratio of the absorption factors would be used in the exposure equation.

4.1.1. Drinking Water

Figure 4-1 presents two wildlife oral exposure equations corresponding to two patterns of contamination of water:

(1) the animal obtains some of its drinking water from a contaminated source and the remainder from uncontaminated sources; and

(2) the animal consumes drinking water from several sources contaminated at different levels.

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[a]The frequency term should be estimated with care. For example, if a feature attractive to wildlife is contaminated, an animal may spend a proportionally longer time in the contaminated area. Similarly, if only part of an animal's theoretical foraging range has suitable habitat, the animal may spend more time feeding in that habitat. Finally, animals may avoid areas or media with contamination they can detect.

Figure 4-1. Wildlife Dose Equations for Drinking Water Exposures

One Source of Contamination

$$ADD_{pot} = C \times FR \times NIR \qquad [4\text{-}6]$$

Different Sources With Varying Levels of Contamination

$$ADD_{pot} = \sum_{i=1}^{n} (C_i \times FR_i) \times NIR \qquad [4\text{-}7]$$

ADD_{pot} = Potential average daily dose (e.g., in mg/kg-day).

C = Average contaminant concentration in a single water source (e.g., in mg/L or in mg/kg, because 1 liter of water weighs 1 kg).

FR = Fraction of total water ingestion from the contaminated water source (unitless).

NIR = Normalized water ingestion rate (i.e., fraction of body weight consumed as water per unit time; e.g., in g/g-day)

and

C_i = Average contaminant concentration in the i^{th} water source (e.g., in mg/L).

FR_i = Fraction of water consumed from the i^{th} water source (unitless).

n = Number of contaminated water sources.

In the first case, the distribution and mean value of the contaminant concentration in the one source could be determined. In the second case, the different water sources are likely to be characterized by different mean levels of contamination, and consumption from these sources would be weighted by the fraction (FR_i) of the animal's total daily water ingestion obtained from each source. FR (or FR_i) in Figure 4-1 is a function of the degree of overlap of the contaminated water source(s) and the animal's home range. If the area of the contaminated water source is larger than the typical home range for the species, FR could

equal one for many individuals. The number of individuals for which FR equals one could be estimated from information on population density, distribution, and social structure. For large, mobile animals, the area of contamination may be smaller than the area over which a single animal is likely to move. In these cases, FR for an animal with the contaminated area entirely within its home range can be estimated using information on the home range, attributes of the contaminated area, and drinking behavior of the animal. Home range estimates should be used with care because (1) the area in which an animal moves varies with several factors, including reproductive status, season, and habitat quality; (2) most animals do not drink or feed randomly within their home range; (3) the term home range has been used inconsistently in the literature; and (4) estimates of home range can vary substantially with the measurement technique used. In this Handbook and accompanying Appendix, we have tried to identify clearly which estimates of home range correspond to a daily activity and foraging home range.

When using home range data, we recommend that users consult the Appendix tables for the species of interest to become familiar with how estimates of home range size vary with geographic area, season, type of habitat, animal reproductive status, and measurement technique. The Appendix tables provide both the sample size and a brief description of the method used to estimate home range size, which can help indicate the robustness of an estimate and whether it is likely to over- or underestimate home range size. For mark-and-recapture studies, the number of recaptures per animal is provided when possible to assist the user in determining the degree to which the reported values may underestimate true home range size. If a study indicated that the home range estimate is likely to include areas outside of the animals' usual activity range (e.g., distant egg-laying sites used only once per season), this would be noted in the Appendix tables, and the value would not be included in Chapter 2. Some animals use a fixed "home base" some distance from feeding grounds such as a rookery. For these animals, we have reported foraging radius (the distance they will travel to a feeding area). Foraging radius can be used to determine whether the animal might feed or drink in a given contaminated area.

4.1.2. Diet

Wildlife can be exposed to contaminants in one or more components of their diet, and different components can be contaminated at different levels. In this section, we outline methods of estimating food ingestion rates that allow total doses to be estimated when different components of the diet are contaminated, either at similar or different levels (Section 4.1.2.1). We also provide data on caloric content of foods and assimilation efficiencies that can be used in the dose equations provided (Section 4.1.2.2).

4.1.2.1. Dose Equations

Figure 4-2 presents a generic equation for estimating oral doses of contaminants in food for wildlife species. FR_k is a function of the degree of overlap of the k^{th} type of simplest case, the normalized ingestion rate for each food type, NIR_k, is known on a wet-

Figure 4-2. Wildlife Dose Equations for Dietary Exposures

$$ADD_{pot} = \sum_{k=1}^{m} (C_k \times FR_k \times NIR_k) \qquad [4\text{-}8]$$

ADD_{pot}	=	Potential average daily dose (e.g., in mg/kg-day).
C_k	=	Average contaminant concentration in the k^{th} type of food (e.g., in mg/kg wet weight).
FR_k	=	Fraction of intake of the k^{th} food type that is contaminated (unitless). For example, if the k^{th} component of an animal's diet were salmon, FR_k for salmon would equal the fraction of the salmon consumed that is contaminated at level C_k. If all of the salmon consumed were contaminated at level C_k, then FR_k would equal one.
NIR_k	=	Normalized ingestion rate of the k^{th} food type on a wet-weight basis (e.g., in g/g-day).
m	=	Number of contaminated food types.

contaminated forage or prey and the animal's home range (see Section 4.1.1). In the weight basis, and Equation 4-8 can be used directly. In many cases, however, NIR_k is unknown or has been determined for laboratory diets that differ significantly from natural diets in terms of caloric value per unit wet weight. Ingestion rates based on relatively dry laboratory diets might underestimate the amount of food a free-living animal consumes.

There are several ways to estimate NIR_k, depending on the type of information that is available. If dietary composition is expressed as the number of each prey type captured on a daily basis (N_k), estimating the normalized ingestion rate for each prey type (NIR_k) requires only one step:

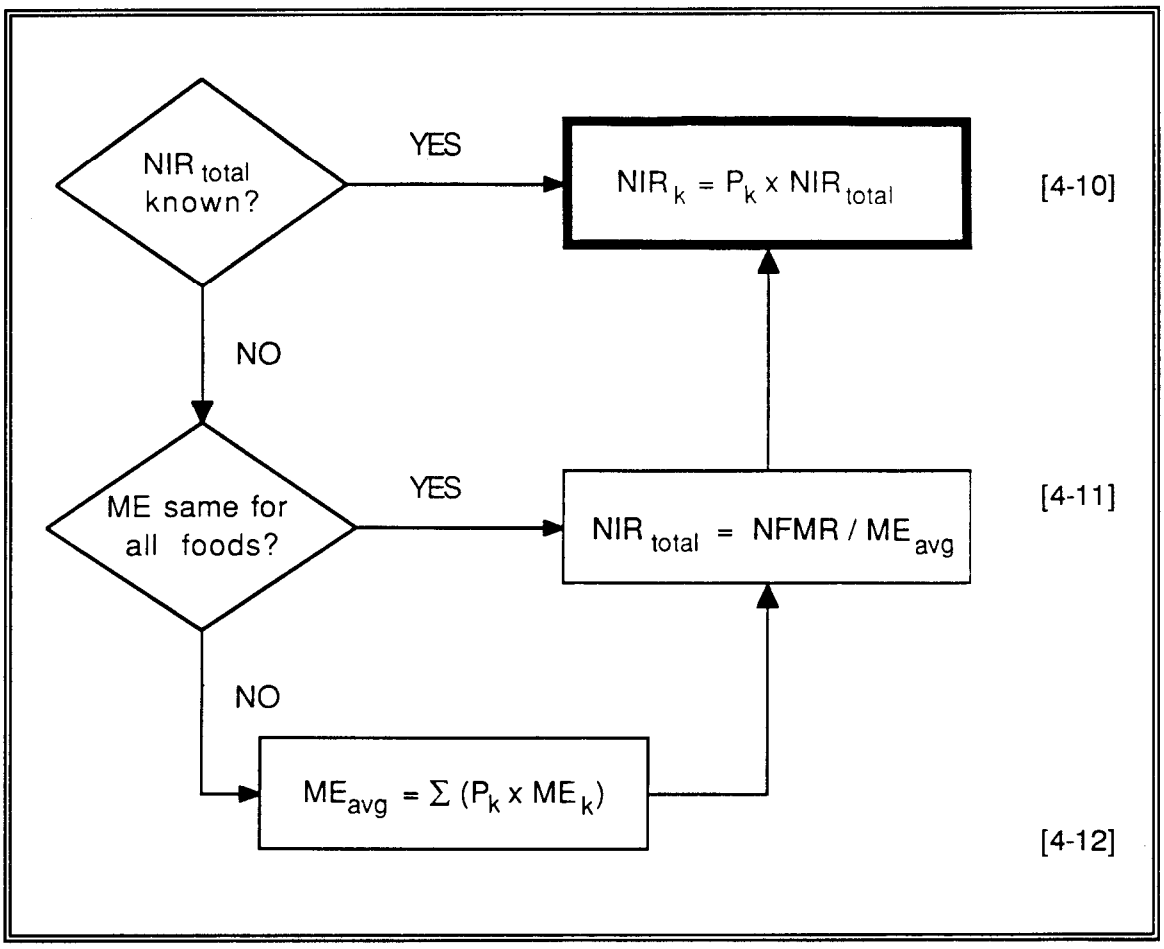
$$NIR_k = (N_k \times Wt_k) / BW \qquad [4\text{-}9]$$

where Wt_k is the body weight of the k^{th} prey type and BW is the body weight of the predator.

Figure 4-3 presents a flow chart depicting equations that can be used if the proportion of the diet for a given food type has been measured or estimated on a wet-weight basis. These equations may require estimates of the free-living metabolic rate (FMR) of the organism and the metabolizable energy (ME) of the organism's forage or prey. Estimated FMRs can be found in the species profiles in Chapter 2, and allometric equations for estimating FMR on the basis of body weight are provided in Chapter 3 (Section 3.5). ME should be averaged over the food types when ME on a wet-weight basis (e.g., cal/g wet weight) differs substantially among the different foods. Section 4.1.2.2 describes how to estimate ME.

A common situation facing someone conducting a wildlife exposure assessment for predators is that in a key study, dietary composition is expressed as a percentage of the total number of prey captured over a period of time instead of as a percentage of the total wet weight of food ingested daily. Because some prey can be substantially larger than others (e.g., rabbits compared with voles), and because ME of different types of prey may

Figure 4-3. Estimating NIR_k When Dietary Composition Is Known on a Wet-Weight Basis



NIR_{total} = Total normalized ingestion rate (e.g., in g/g-day).
NIR_k = Normalized ingestion rate of the k^{th} food type (e.g., in g/g-day).
P_k = Proportion of diet consisting of the k^{th} food type on a wet-weight basis (unitless).
ME_{avg} = Average metabolizable energy of the total diet on a wet-weight basis (e.g., in kcal/g wet weight).
ME_k = Metabolizable energy of the k^{th} food type on a wet-weight basis (e.g., in kcal/g wet weight).
NFMR = Free-living metabolic rate normalized to body weight (e.g., in kcal/g-day).

differ, the steps outlined in Figure 4-4 may be needed to estimate prey-specific ingestion rates. First, one calculates the ME of each prey type. Then, one determines the average number of prey (N_{avg}) captured daily on the basis of the metabolic needs of the predator

Figure 4-4. Estimating NIR_k Based on Different ME Values When Dietary Composition Is Expressed as Percentage of Total Prey Captured

Step 1: Calculate the metabolizable energy (ME) content of each prey or food type on a wet-weight basis:

$$ME(\text{wet wt})_k = GE(\text{wet wt})_k \times AE_k \quad [4\text{-}13]$$

Step 2: Estimate the average number of prey (or other food items) consumed each day:

$$N_{avg} = FMR / (\text{weighted average prey ME})$$

$$N_{avg} = FMR / \left(\sum_{k=1}^{m} PN_k \times Wt_k \times ME(\text{wet wt})_k\right) \quad [4\text{-}14]$$

Step 3: Calculate IR_k:

$$IR_k = N_{tot} \times PN_k \times Wt_k \quad [4\text{-}15]$$

Step 4: Normalize to body weight:

$$NIR_k = IR_k / BW \quad [4\text{-}16]$$

$ME(\text{wet wt})_k$	=	Metabolizable energy in the k^{th} prey or food type (e.g., in kcal/g wet weight).
$GE(\text{wet wt})_k$	=	Gross energy content of the k^{th} food type (e.g., in kcal/g wet weight).
AE_k	=	Assimilation efficiency for the species for the k^{th} food type (unitless).
N_{avg}	=	Average number of prey (or other food items) eaten each day.
FMR	=	Free-living metabolic rate (e.g., in kcal/day).
m	=	Number of different types of prey or other foods.
PN_k	=	Proportion of the total number of prey that is composed of the k^{th} prey type (unitless). It often is the case that larger numbers of relatively small prey and smaller numbers of relatively large prey are captured. (If the total number of prey of each type captured each day are reported in the literature, calculations of IR_k are very simple [i.e., $N_k \times Wt_k$] and steps 1 and 2 are unnecessary.)
Wt_k	=	Body weight of an individual of the k^{th} food type (e.g., in g).
IR_k	=	Ingestion rate of the k^{th} food type (e.g., in g/day).

and the weighted average ME of the prey. Given N_{avg} , the ingestion rate for each prey type (IR_k) can be computed on a wet-weight basis and normalized to body weight (NIR_k). Because N_{avg} is estimated using prey weight, different sizes of the same prey species (e.g., smaller and larger fish) should be separated into appropriate size intervals to reduce uncertainty in the estimate.

4.1.2.2. Energy Content and Assimilation Efficiencies

The total or gross energy (GE) content of a food type is a function only of characteristics of the food. On the other hand, metabolizable energy (ME) depends on characteristics of both the food and the organism eating it. To clarify the meaning of ME, Figure 4-5 presents a flow chart of energy utilization by animals. Digestible energy in a diet is GE consumed minus the energy lost as feces; digestible energy efficiency (DE) is digestible energy divided by GE. ME is GE consumed minus the energy lost as both feces and urine. Assimilation efficiency (AE, also called metabolizable energy efficiency) is ME divided by GE. Rearranging this relationship, ME is equal to GE of the diet multiplied by the animal's AE for the diet as shown in Figure 4-6, Equation 4-17. General ME values can be found in Table 3-1 or more specific ones calculated from GE content of the food and the AE of the animal eating that food, as discussed below.

The GE content of food typically is reported using one (or more) of three measures: (1) energy per unit total dry weight, (2) energy per unit ash-free dry weight, or (3) energy per unit fresh biomass (i.e., per unit wet weight) (Górecki, 1975). Caloric content per unit total dry weight is obtained directly from the combustion of dried material in a calorimeter. Ash-free dry weight is the dry weight after subtracting the ash content.[b] The ash-free dry-weight caloric value exceeds the total dry-weight caloric value by the ratio of the total dry weight to the ash-free dry weight. Typically, animal (exclusive of thick shells) and plant materials are 1 to 10 percent ash on a wet-weight basis and 5 to 30 percent ash on a dry-weight basis (Ashwell-Erickson and Elsner, 1981; Cummins and Wuycheck, 1971;

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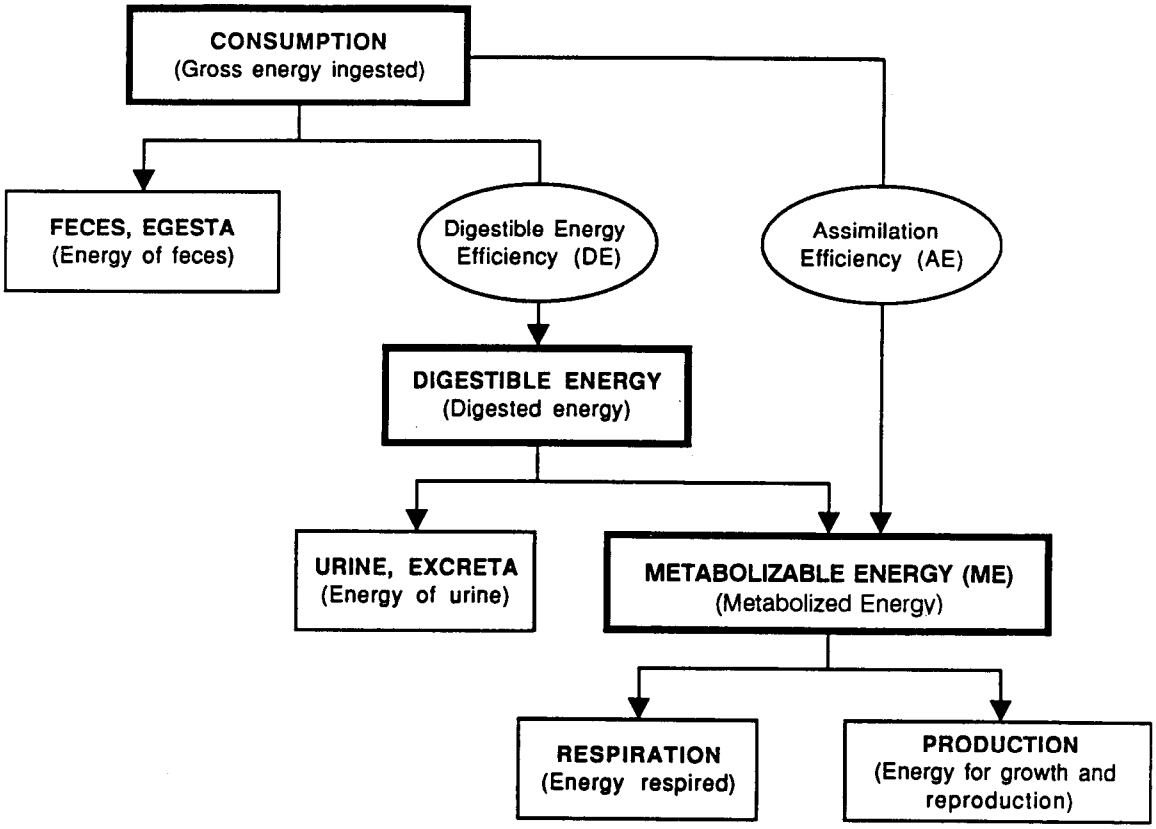
[b] **Ash constituents typically include calcium carbonate (e.g., shell), calcium phosphate (vertebrate bone), and hydrated silica salts.**

Figure 4-5. Utilization of Food Energy by Animals



Source: Adapted from Grodzinski and Wunder, 1975.

Figure 4-6. Metabolizable Energy (ME) Equation

$$ME = GE \times AE \quad [4\text{-}17]$$

where:

ME = Metabolizable energy (e.g., in kcal/g)

GE = Gross energy (e.g., in kcal/g)

AE = Assimilation efficiency (unitless)

This Handbook assumes ME and GE are estimated on a wet-weight basis. To estimate ME or GE of the k^{th} food type on a wet-weight basis from dry-weight measurements, the following equations can be used:

$$GE(\text{wet wt})_k = GE(\text{dry wt})_k \times (1 - \text{proportion water}_k) \text{ or} \quad [4\text{-}18]$$

$$GE(\text{wet wt})_k = GE(\text{dry wt})_k \times (\text{dry weight}_k/\text{wet weight}_k) \quad [4\text{-}19]$$

and

$$ME(\text{wet wt})_k = ME(\text{dry wt})_k \times (1 - \text{proportion water}_k) \text{ or} \quad [4\text{-}20]$$

$$ME(\text{wet wt})_k = ME(\text{dry wt})_k \times (\text{dry weight}_k/\text{wet weight}_k) \quad [4\text{-}21]$$

Hunt, 1972). The ash content of the diet is not metabolized and thus does not provide energy to the animal. Figure 4-6 (Equations 4-18 through 4-21) illustrates how the caloric content per unit of fresh biomass can be obtained by adjusting the dry-weight value based on the water content of the biomass.

A summary of GE contents of many wildlife food types are presented in Tables 4-1 (animals) and 4-2 (plants), on both a wet-weight and a dry-weight basis. Caloric content of a given species on a wet-weight basis tends to be more variable than caloric content on a dry-weight basis because plants, and to a lesser degree animals, vary in their water content depending on environmental conditions. Ash-free dry-weight caloric values are not presented because it is not appropriate to use them with the equations and AEs in this chapter. Ash contents are accounted for in the AEs presented in Table 4-3.

Table 4-1. Gross Energy and Water Composition of Wildlife Foods: Animal Prey (values expressed as mean [standard deviation]^n where n = number of studies)

Type of food	kcal/g wet wt	% H_20	kcal/g dry wt	References
Aquatic				
invertebrates				
bivalves (without shell)	0.80	82 (4.5)[3]	4.6 (0.35)[4]	1,2,3,4,5,6
crabs (with shell)	1.0 (0.21)[5]	74 (6.1)[5]	2.7 (0.45)[4]	1,2,3,7
shrimp	1.1 (0.24)[4]	78 (3.3)[7]	4.8 (0.31)[6]	1,3,4,6,7
isopods, amphipods	1.1	71-80	3.6 (0.78)[3]	4,6,7
cladocerans	0.74	79-87	4.8 (0.62)[14]	2,4
insect larvae			5.3 (0.37)[8]	1,4
vertebrates				
bony fishes	1.2 (0.24)[18]	75 (5.1)[18]	4.9 (0.38)[18]	7
Pacific herring	2.0 (0.43)[3]	68 (3.9)[3]	6.1 (0.50)[4]	8,9
small fish (e.g., bluegill)			4.1 (0.47)[3]	1,7
Terrestrial				
invertebrates				
earthworms[a]	0.78-0.83	84 (1.7)[3]	4.6 (0.36)[4]	1,7
grasshoppers, crickets	1.7 (0.26)[3]	69 (5.6)[11]	5.4 (0.16)[4]	1,10,11
beetles (adult)	1.5	61 (9.8)[5]	5.7-5.9	1,10,11
mammals				
mice, voles, rabbits	1.7 (0.28)[14]	68 (1.6)[4]	5.0 (1.3)[17]	12,13,14
birds				
passerines				
with peak fat reserves[b]			7.8 (0.18)[10]	15
with typical fat reserves	1.9 (0.07)[3]	68	5.6 (0.34)[13]	10,14,15,16
mallard (flesh only)	2.0	67	5.9	10
gulls, terns	1.9		4.4	1
reptiles and amphibians				
snake, lizards	1.4	66	4.5 (0.28)[5]	14,17
frogs, toads	1.2	85 (4.7)[3]	4.6 (0.45)[3]	12,14

Note: For Tables 4-1 and 4-2, a single value represents the results of a single study on one species, and should not be interpreted as a mean value or a value indicating no variation in the category. Two values separated by a hyphen indicate that values were obtained from only two studies.

[a]Not including soil in gut, which can constitute one-third of the wet weight of an earthworm.
[b]Peak fat reserves occur just prior to migration. Typical fat reserves are for resident passerines or migratory species during nonmigratory seasons.

References: (1) Cummins and Wuycheck, 1971; (2) Golley, 1961; (3) Tyler, 1973; (4) Jorgensen et al., 1991; (5) Pierotti and Annett, 1987; (6) Minnich, 1982; (7) Thayer et al., 1973; (8) Ashwell-Erickson and Elsner, 1981; (9) Miller, 1978; (10) Collopy, 1975; (11) Bell, 1990; (12) Górecki, 1975; (13) Golley, 1960; (14) Koplin et al., 1980; (15) Odum et al., 1965; (16) Duke et al., 1987; (17) Congdon et al., 1982.

Table 4-2. Energy and Water Composition of Wildlife Foods: Plants (values expressed as mean [standard deviation]^n where n = number of studies)

Type of food	kcal/g wet wt[a]	% H_20	kcal/g dry wt	References
Aquatic				
algae	0.41-0.61	84 (4.7)[3]	2.36 (0.64)[4]	1,2,3
aquatic macrophytes		87 (3.1)[3]	4.0 (0.31)[12]	1,2,4
emergent vegetation		[45-80][b]	4.3 (0.13)[3]	1,2,4
Terrestrial				
monocots				
young grasses	1.3	70-88	4.2	5,6
mature dry grasses		7-10	4.3 (0.33)[5]	1,5,7,8
dicots				
leaves		85 (3.5)[3]	4.2 (0.49)[57]	9
roots			4.7 (0.43)[52]	9
bulbs, rhizomes			3.6 (0.68)[3]	2,7,10
stems, branches			4.3 (0.34)[51]	9
seeds		9.3 (3.1)[12]	5.1 (1.1)[57]	6,9,11,12
fruit				
pulp, skin	1.1 (0.30)[3]	77 (3.6)[3]	2.0 (3.4)[28]	10,13
pulp, skin, seeds			2.2 (1.6)[10]	10

Note: For Tables 4-1 and 4-2, a single value represents the results of a single study on one species, and should not be interpreted as a mean value or a value indicating no variation in the category. Two values separated by a hyphen indicate that values were obtained from only two studies.

[a] **Few determinations of the energy content of plants have been made on a wet-weight basis because plants fluctuate widely in water content depending on environmental conditions.**

[b] **Values in brackets represent total range of field measurements, instead of values from only two studies, as for the remainder of the table. Buchsbaum and Valiela (1987) found the water content of the emergent marsh vegetation *Spartina alterniflora*, *S. patens*, and *Juncus gerardi* to decrease over a summer from 80 to 60 percent, 70 to 45 percent, and 78 to 61 percent, respectively, as the marsh dried. In contrast, they found a submerged macrophyte to maintain water content within a few percent throughout the season.**

References: (1) Cummins and Wuycheck, 1971; (2) Jorgensen et al., 1991; (3) Minnich, 1982; (4) Boyd and Goodyear, 1971; (5) Davis and Golley, 1963; (6) Drozdz, 1968; (7) Golley, 1960; (8) Kendeigh and West, 1965; (9) Golley, 1961; (10) Karasov, 1990; (11) Dice, 1922; (12) Robel et al., 1979; (13) Levey and Karasov, 1989.

Table 4-3. General Assimilation Efficiency (AE) Values (values expressed as mean [standard deviation]^n where n = number of studies)

Group	Prey/Forage	AE %	Reference
Birds			
	animals		
birds of prey	**birds, small mammals**	**78 (5.2)[16]**	**1,2,3,4**
eagles, seabirds	**fish**	**79 (4.5)[9]**	**1,2,4,5**
waterfowl	**aquatic invertebrates**	**77 (8.4)[3]**	**1**
birds	**terrestrial insects**	**72 (5.1)[16]**	**1,5,6**
	plants		
passerines	**wild seeds**	**75 (9)[11]**	**1**
non-passerines	**wild seeds**	**59 (13)[25]**	**1**
birds	**cultivated seeds**	**80 (8)[17]**	**1**
birds	**fruit pulp, skin**	**64 (15)[31]**	**1**
birds	**fruit pulp, skin, seeds**	**51 (15)[22]**	**1**
birds	**grasses, leaves**	**47 (9.6)[3]**	**1***
grouse, ptarmigans	**stems, twigs, pine needles**	**34 (5.3)[8]**	**1,1**
geese	**emergents (e.g., spartina)**	**39 (9.1)[4]**	**1***
ducks	**aquatic vegetation**	**23 (5.3)[5]**	**1***
geese, grouse	**bulbs, rhizomes**	**56 (18)[4]**	**1**
Mammals			
	animals		
pinnipeds	**fish**	**88 (1.1)[5]**	**7,8**
mammals	**small birds, mammals**	**84 (6.5)[4]**	**9,10,11**
mammals	**fish**	**91**	**12**
small mammals	**insects**	**87 (4.9)[6]**	**11,13**
	plants		
voles, mice	**seeds, nuts**	**85 (7.3)[8]**	**11,14**
lemmings, voles	**mature grasses**	**41 (9.1)[5]**	**15**
rabbits, voles, mice	**green forbs**	**73 (7.6)[8]**	**11,14,15**
rabbits, voles, rats	**"herbivory"**	**76 (7.6)[5]**	**11,14,16**

References: (1) Karasov, 1990; (1*) calculated from data presented in Appendix I of Karasov, 1990; (2) Stalmaster and Gessaman, 1982; (3) Koplin et al., 1980; (4) Castro et al., 1989; (5) Ricklefs, 1974; (6) Bryant and Bryant, 1988; (7) Ashwell-Erickson and Elsner, 1981; (8) Miller, 1978; (9) Litvaitis and Mautz, 1976; (10) Vogtsberger and Barrett, 1973; (11) Grodzinski and Wunder, 1975; (12) estimated by dividing 4.9 kcal/g gross energy for bony fishes (Table 4-1) by metabolizable energy of 4.47 reported for fish consumed by mammals (Nagy, 1987); (13) Barrett and Stueck, 1976; (14) Drozdz, 1968; (15) Batzli and Cole, 1979; (16) Drozdz et al., 1971.

Table 4-3 summarizes AEs for several different types of foods and species. Assimilation efficiency is a function of both the consumer species' physiology and the type of diet. Factors that reduce many species' ability to assimilate the energy contained in food include the ash content of the diet and the percentage of relatively indigestible organic materials such as chitin (arthropods) or cellulose (plants). The higher the ash content, the lower the AE, all else being equal.

Fat content also influences GE. For example, carbohydrates (approximately 4.3 kcal/g) and proteins (approximately 5.7 kcal/g) typically provide about half as many calories per gram as fat (approximately 9.5 kcal/g) (Peters, 1983). Thus, small changes in fat content of animal tissues or plant seeds cause significant changes in their caloric value. For example, just prior to fall migration, passerine birds have achieved peak fat deposition and average 7.8 kcal/g dry weight. Non-migrating passerines (i.e., permanent residents or migratory species during nonmigrating seasons) average only 5.6 kcal/g dry weight. Two references with substantial compilation of data on caloric content of biological materials are Jorgensen et al. (1991) and Cummins and Wuycheck (1971). The latter includes extensive data on invertebrates.

Figure 4-7 provides a sample calculation of food ingestion rates using the methodology outlined above.

4.1.3. Soil and Sediment Ingestion

In this section, we review information on the ingestion of soil and sediment for the species included in this Handbook (and similar species). Despite the potential importance of soil and sediment ingestion as a route of exposure of wildlife to environmental contaminants, data to quantify these ingestion rates are limited at this time.

Figure 4-7. Example of Estimating Food Ingestion Rates for Wildlife Species From Free-Living Metabolic Rate and Dietary Composition: Male Mink

1. **Estimate Field Metabolic Rate (FMR) [Equation 3-47]**

$$FMR\ (kcal/day) = 0.6167\ (g\ Wt)^{0.862}$$
$$= 0.6167\ (1{,}040)^{0.862}$$
$$= 246\ (kcal/day)$$

2. **Normalize to Body Weight (Wt) [Equation 3-40]**

$$NFMR\ (kcal/g\text{-}day) = 246\ (kcal/day)/1{,}040\ (g\ Wt)^{a}$$
$$= 0.24\ (kcal/g\text{-}day)$$

3. **Estimate Average Metabolizable Energy (ME_{avg}) of Diet [Equation 4-12]**

Dietary Item (k=5)	Proportion of Diet (P_k)[b]	Gross Energy (GE_k)[c] (kcal/g wet wt)	Assimilation Efficiency (AE_k)[d]	Metabolizable Energy (ME_k) (kcal/g wet wt) ($ME_k = GE_k \times AE_k$)	($P_k \times ME_k$)
Fish	0.85	1.2	0.91	1.1	0.93
Crustacea	0.04	1.1	0.87	0.96	0.038
Amphibia	0.03	1.2	0.91	1.1	0.033
Birds/ Mammals	0.06	1.8	0.84	1.5	0.090
Vegetation	0.02	1.3	0.73	0.95	0.019
ME_{avg} (kcal/g wet wt) = $\sum(P_k \times ME_k)$ = 1.1[e]					

4. **Estimate Total Normalized Ingestion Rate (NIR_{total}) [Equation 4-11]**

$$NIR_{total}\ (g/g\text{-}day) = \frac{0.24\ (kcal/g\text{-}day)}{1.1\ (kcal/g\ wet\ wt)\ (i.e.,\ ME_{avg})}$$
$$= 0.22\ (g/g\text{-}day)$$

5. **Estimate Prey-specific Normalized Ingestion Rates (e.g., NIR_{fish}) [Equation 4-10]**

$$NIR_{fish}\ (g/g\text{-}day) = 0.85\ (P_{fish}) \times 0.22\ (g/g\text{-}day)$$
$$= 0.19\ (g/g\text{-}day)$$

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[a] Body weight for Montana population in the summer (Mitchell, 1961).
[b] Dietary composition based on Alexander (1977).
[c] Values from Tables 4-1 and 4-2 (for vegetation, assuming value for young grasses).
[d] Values from Table 4-3 (for vegetation, assuming green forbs; for crustacea, assuming equivalent AE for insects; for amphibia, assuming equivalent to mammals consuming fish).
[e] In this example, ME_{avg} is the same as the ME value for fish, which comprises 85 percent of the diet.

4.1.3.1. Background

Soil is ingested both intentionally and incidentally by many species of wildlife and can be a significant exposure pathway for some contaminants (Arthur and Alldredge, 1979; Garten, 1980). Many ungulates deliberately eat soil to obtain nutrients; some may travel a considerable distance to reach certain areas (salt licks) that are used by many animals. Some birds gather mud in their beaks for nest-building, and others consume it for calcium (Kreulen and Jager, 1984). Many animals can incidentally ingest soil while grooming, digging, grazing close to the soil, or feeding on items that are covered with soil (such as roots and tubers) or contain sediment (such as molluscs). Earthworms ingest soil directly; the soil in their guts may be an important exposure medium for animals that eat these organisms (Beyer et al., 1993).[c]

Soil ingestion rates have been estimated for only a few wildlife species and were not available in the published literature for most of the animals in this Handbook. The percentage of soil ingested is often estimated from the acid-insoluble ash content of wildlife scats or digestive tract contents. Scat analysis on small animals is often difficult because scat are small. Soil ingestion by large mammals also has been estimated using insoluble chemical tracers (Mayland et al., 1977) and using standard x-ray diffraction analysis (Garten, 1980).

4.1.3.2. Methods

Garten (1980) estimated the amount of soil in the gastrointestinal (GI) tract of a small mammal (the hispid cotton rat) using the following equation:

$$I = (S - F)W \qquad [4\text{-}22]$$

---

[c]**Seed-eating birds often consume "grit" to aid in digestion, which makes them vulnerable to poisoning by granular formulations of pesticides and fertilizers. In this section, however, we restrict our discussion to soils and sediments, which are composed of much smaller particle sizes.**

where I equals the amount of soil in the GI tract, S equals the ratio of insoluble ash to dry contents in the GI tract, F equals the ratio of insoluble ash to dry contents in fescue (the dominant vegetation in the rat's habitat), and W equals the dry weight of GI-tract contents.

It is also possible to estimate soil ingestion rates from the acid-insoluble ash content of the animal's scat because the percentage of acid-insoluble ash in mineral soil is much higher (usually at least 90 percent) than in plant or animal tissue (usually no more than a few percent). Beyer et al. (in press) used scat samples to estimate the fraction of soil in the diet for several species. The equation for this estimation approach is slightly more complicated than Equation 4-22, because it accounts for digestibility and the mineral content of the soil. They found a significant correlation between the measured and predicted relationships of the ratio of acid-insoluble ash to dry weight of scat and the percentage of soil in the diet.

4.1.3.3. Results

Percent soil in the diet for some of the selected and similar species included in Chapter 2 are included in Tables 4-4 and 4-5. Of the species studied, the sandpiper group, which feeds on mud-dwelling invertebrates, was found to have the highest rates of soil/sediment ingestion (30, 18, 17, and 7.3 percent of diet, respectively, for semipalmated, western, stilt, and least sandpipers, although only a single sample was analyzed for each species). Wood ducks also can ingest a high proportion of sediment (24 percent) with their food. Relatively high soil intakes were estimated for the raccoon (9.4 percent), an omnivore, and the woodcock (10.4 percent), which feeds extensively on earthworms. Other species that eat earthworms might be expected to exhibit similarly high soil intakes. The Canada goose, which browses on grasses, also exhibited a high percentage of soil in its diet (8.2 percent). Soil ingestion was lowest for the white-footed mouse, meadow vole, fox, and box turtle (<2, 2.4, 2.8, and 4.5 percent, respectively). Box turtles, tortoises, and other reptiles, however, have been known to intentionally ingest soil, perhaps for its nutrient content (Kramer, 1973; Sokal, 1971). Beyer et al.'s (in press) data should be used with caution, because error was introduced by estimating variables in

Table 4-4. Percent Soil or Sediment in Diet Estimated From Acid-Insoluble Ash of Scat

Species	Scat Samples[a]	% Insoluble Ash Mean (SE)	Range	Estimated % Digestibility of Diet	Estimated Percent Soil in Diet (dry weight)
Birds					
Canada goose	23	12 (1.5)	3.9 - 38	25	8.2
Mallard	88	6.9 (1.1)	0.36 - 47	30	<2
Wood duck	7	24 (13)	0 - 75	60	11
Blue-winged teal	12	2.3 (0.36)	0.72 - 5.1	60	<2
Ring-necked duck	6	0.72 (5.5)	0.50 - 1.2	60	<2
American woodcock	7	22 (5.5)	6.3 - 40	55	10.4
Semipalmated sandpiper	1	56		70	30
Western sandpiper	1	42		70	18
Stilt sandpiper	1	40		70	17
Least sandpiper	1	24		70	7.3
Mammals					
Red fox	7	14 (2.6)	4.8 - 25	70	2.8
Raccoon	4	28 (8.9)	13 - 50	70	9.4
White-footed mouse	9	8.5 (0.71)	5.7 - 11	65	<2
Meadow vole	7	8.9 (1.2)	4.2 - 14	55	2.4
Reptiles and Amphibians					
Eastern painted turtle	9	21 (2.9)	11 - 41	70	5.9
Box turtle	8	18 (6.5)	3.6 - 49	70	4.5

[a]For the sandpipers, the white-footed mouse, and the meadow vole, scat samples from more than one animal had to be combined into one sample to provide sufficient quantity for chemical analysis.

Source: Adapted from Beyer et al. (in press).

Table 4-5. Other Estimates of Percent Soil or Sediment in Diet

Species	Estimated % soil in diet (dry weight)	Reference
Jackrabbit	6.3	Arthur and Gates 1988
Hispid cotton rats	2.8	Garten 1980
Shorebirds	10-60	Reeder 1951

the equation (e.g., digestibility) and by the small samples they obtained from some of the smaller animals.

Other studies of soil ingestion by species similar to those presented in this Handbook are summarized in Table 4-5. Sediment has been found in the stomachs of white-footed mice (Garten, 1980) and ruddy ducks and shovelers (Goodman and Fisher, 1962). Sediment in the gut of tadpoles inhabiting highway drainages may be responsible for high concentrations of lead detected in these organisms (Birdsall et al., 1986).

4.1.3.4. Dose Equations

To estimate exposures to contaminants in soils or sediments from the data provided in Tables 4-4 and 4-5, Equation 4-23 (Figure 4-8) can be used. If the percent soil in the diet is measured on a dry-weight basis, as it usually is, total dietary intake should also be expressed on a dry-weight basis.

4.1.4. Air

Inhalation toxicity values and exposure estimates are usually expressed in units of concentration in air (e.g., mg/m^3) rather than as average daily doses. Assessment of the inhalation pathway becomes complicated if the toxicity values must be extrapolated from a test species (e.g., rat) to a different species (e.g., shrew). Inhalation toxicologists extrapolate toxicity values from species to species on the basis of the dose deposited and retained in the respiratory tract (the dose that is available for absorption, distribution,

Figure 4-8. Wildlife Oral Dose Equation for Soil or Sediment Ingestion Exposures

$$ADD_{pot} = \left(\sum_{k=1}^{m} (C_k \times FS \times IR_{total}(\text{dry weight}) \times FR_k)\right)/BW \qquad [4\text{-}23]$$

ADD_{pot} = Potential average daily dose (e.g., in mg/kg-day).

C_k = Average contaminant concentration in soils in the k^{th} foraging area (e.g., in mg/kg dry weight).

FS = Fraction of soil in diet (as percentage of diet on a dry-weight basis divided by 100; unitless).

IR_{total} = Food ingestion rate on a dry-weight basis (e.g., in kg/day). Nagy's (1987) equations for estimating FI rates on a dry-weight basis (presented in Section 3.1) can be used to estimate a value for this factor. If the equations for estimating FI rates on a wet-weight basis presented in Section 4.2 are used, conversion to ingestion rates on a dry-weight basis would be necessary.

FR_k = Fraction of total food intake from the k^{th} foraging area (unitless).

BW = Body weight (e.g., in kg).

m = Total number of foraging areas.

metabolism, and elimination). Once the appropriate toxicity benchmark (in terms of dose) has been estimated for the species of concern (e.g., shrew), the corresponding air concentration is estimated based on the respiratory physiology of that species. EPA uses this approach because it can account for nonlinear relationships between exposure concentrations, inhaled dose, and dose to the target organ(s). Because of the complexities associated with the extrapolations, an inhalation toxicologist should be consulted when assessing this pathway.

The dose deposited, retained, and absorbed in the respiratory tract is a function of species anatomy and physiology as well as physicochemical properties of the contaminant. The assessor will need to consider factors such as the target species' airway

size, branching pattern, breathing rate (volume and frequency), and clearance mechanisms, as well as whether the contaminant is a gas or aerosol and whether its effects are systemic or confined to the respiratory tract. Key information on the contaminant includes particle size distribution (for aerosols), temperature and vapor pressure (for gaseous agents), and pharmacokinetic data (e.g., air/blood partition coefficients, metabolic parameters). While physiologically based pharmacokinetic models have been useful for these calculations, they are available for only a few laboratory species. These issues are discussed in detail in *Interim Methods for Development of Inhalation Reference Concentrations* (U.S. EPA, 1990). Although the document specifically describes how to calculate inhalation reference concentrations for humans, the principles are useful for any air-breathing species.

4.1.5. Dermal Exposure

Dermal toxicity values and exposure estimates are usually expressed as an absorbed dose resulting from skin contact with a contaminated medium. This exposure pathway can be of great importance to wildlife, particularly when an animal is directly sprayed (Driver et al., 1991). Dermal exposures may also be a concern for wildlife that swim or burrow. Dermal absorption of contaminants is a function of chemical properties of the contaminated medium, the permeability of the animals' integument, the area of integument in contact with the contaminated medium, and the duration and pattern of contact. A full discussion of quantifying absorbed dose through the skin is beyond the scope of this document, and many of the required parameters have not been measured for wildlife species. Readers interested in pursuing this exposure pathway may find useful information in *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992c).

4.2. ANALYSIS OF UNCERTAINTY

In the risk assessment process, several sources of uncertainty should be evaluated, including the uncertainties associated with the exposure assessment and the toxicity

assessment. The following sections discuss three sources of uncertainty related to the exposure assessment: (1) natural variability in the population in question, (2) uncertainty about population parameters as a consequence of limits on sampling the population (i.e., sampling uncertainty), and (3) uncertainty about models used to estimate values. There are other categories of uncertainties associated with site-specific risk assessments that also need to be considered (e.g., selection of substances of concern, data gaps, toxicity assessments). Additional discussion of sources and treatment of uncertainty is available in *Framework for Ecological Risk Assessment* (U.S. EPA, 1992a) and *Guidelines for Exposure Assessment* (U.S. EPA, 1992b). For treatment of site-specific uncertainties in particular, see the *Risk Assessment Guidance for Superfund, Volume I; Human Health Evaluation Manual (Part A) Interim Final* (U.S. EPA, 1989).

4.2.1. Natural Variation

As a review of the data provided in this Handbook makes clear, there is natural variation in the values exhibited by populations for all exposure factors. Population values for some parameters (e.g., body weight) can assume a normal distribution that can be characterized by a mean and variance. We have provided the standard deviation (SD) as the measure of population variance whenever possible. If a risk assessor is concerned with exposures that might be experienced by animals exhibiting characteristics near the extremes of the population's distribution, the SD can be used with the mean value for a normally distributed population to estimate the parameter value for animals with characteristics at specified points in the distribution (e.g., 95th percentile). We also have provided the total range of values reported for each of the exposure factors whenever possible. The ranges can be particularly helpful for parameters that are not normally distributed, such as home-range size.

Another aspect of natural variation, however, is that different populations or the same population at different times or locations can exhibit different mean values for any parameter (e.g., body weight) and even different variances. We have tried to present enough data to give users of the Handbook a feel for the range of values that different populations can assume depending on geographic location, season, and other factors

(e.g., habitat quality). We recommend that risk assessors review the data presented in the Appendix to appreciate the potential for variation in the parameters of interest.

Dietary composition, in particular, can vary markedly with season, location, and availability of prey or forage. The latter factor varies with local conditions and usually is not available for risk assessments. Thus, it can be one of the larger sources of uncertainty in wildlife exposure assessments. State and local wildlife experts might be able to help specify the local dietary habits of a species of concern and should be consulted if screening analyses suggest that exposure at levels of concern is a possibility.

4.2.2. Sampling Uncertainty

Another source of uncertainty in exposure estimates results from limited sampling of populations. Estimates of a population mean and variance become more accurate as the number of samples taken from the population increases. With only a few samples from a population, our confidence that the true population mean is near the estimated mean is low; as the number of samples increases, our confidence increases. The standard error (SE) of the mean is equal to the variance of the population (σ) divided by the square root of the sample size (n). SE can be estimated from the standard deviation of the population divided by the square root of n. SE can be used to calculate confidence limits on an estimate of the mean value for a population. For a normally distributed population, the 95-percent confidence limit of the mean is the estimated mean plus or minus approximately 2 SEs for reasonable sample sizes (e.g., n = at least 20).

Sampling uncertainty occurs in many areas of exposure assessment. Contaminant concentration is one key parameter subject to sampling error. For site-specific risk assessments, as the number of environmental samples increases, the uncertainty about the true distribution of values decreases. Even with large sample sizes, however, this uncertainty can dominate the total uncertainty in the exposure assessment. Other parameters subject to sampling error are the exposure factors presented in this Handbook. One of our criteria for selecting values from the Appendix to include in Chapter 2 was a sample size large enough to ensure that SE was only a few percent of the mean value.

4.2.3. Model Uncertainty

Two main types of models are likely to be used in wildlife exposure assessments: (1) allometric models to predict contact-rate parameters (e.g., food ingestion rates) and (2) fate and transport models to predict contaminant concentrations to which wildlife are exposed.

In this Handbook, we have tried to present statistical confidence limits associated with allometric equations whenever possible. To reduce the confidence limits associated with allometric models, it is important to use a model derived from the smallest and most similar taxonomic/dietary group appropriate for the extrapolation. For example, to estimate a metabolic rate for a red-winged blackbird, it is preferable to use a metabolic rate model derived from data on passerines rather than a model derived from data on many different groups of birds (e.g., raptors, seabirds, geese), and best to use a model for Icterids (the subfamily to which the red-winged blackbird belongs) rather than a model derived from data on passerines.

Uncertainties in exposure models can include how well the exposure model or its mathematical expression approximates the true relationships in the field as well as how realistic the exposure model assumptions are for the situation at hand. Judicious field sampling (e.g., of contaminant concentrations in certain prey species) can help calibrate or confirm estimates in the exposure model (e.g., food-chain exposures). Often a sensitivity analysis can help a risk assessor identify which model parameters and assumptions are most important in determining risk so that attention can be focused on reducing uncertainty in these elements.

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