ES/ER/TM-125

Estimating Exposure of Terrestrial Wildlife to Contaminants

B. E. Sample
G. W. Suter II

DRAFT

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Date Issued—September 1994

Prepared by
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Prepared for
U.S. Department of Energy
Office of Environmental Restoration and Waste Management
under budget and reporting code EW 20

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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ACRONYMS and ABBREVIATIONS

DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
FCAP	Filled Coal Ash Pond
GIS	Geographic Information System
NOAEL	No Observed Adverse Effects Level
ORR	Oak Ridge Reservation
UCL	Upper Confidence Limit
VOC	Volatile Organic Compound

ACKNOWLEDGMENTS

This manuscript benefitted from the review comments of Tom Ashwood and Christopher Welsh. We are also grateful for the assistance of Kit Lash.

EXECUTIVE SUMMARY

This report describes generalized models for the estimation of contaminant exposure experienced by wildlife on the Oak Ridge Reservation. The primary exposure pathway considered is oral ingestion, e.g. the consumption of contaminated food, water, or soil. Exposure through dermal absorption and inhalation are special cases and are not considered hereIN.

Because wildlife are mobile and generally consume diverse diets and because environmental contamination is not spatial homogeneous, factors to account for variation in diet, movement, and contaminant distribution have been incorporated into the models. To facilitate the use and application of the models, life history parameters necessary to estimate exposure are summarized for 15 common wildlife species. Finally, to display the application of the models, exposure estimates were calculated for four species using data from a source operable unit on the Oak Ridge Reservation.

1. INTRODUCTION

This report presents a general model for exposure of terrestrial wildlife to contaminants (Sect. 2), methods for estimating parameters of the model (Sect. 3), species specific parameters for endpoint species on the Oak Ridge Reservation (ORR) (Sect. 4), and a sample application (Sect. 5). Exposure can be defined as the coincidence in both space and time of a receptor and a stressor, such that the receptor and stressor come into contact and interact (Risk Assessment Forum 1992). In the context of ecological risk assessment, receptors include all endpoint species or communities identified for a site [see Suter (1989) and Suter et al. (1994) for discussions of ecological endpoints for waste sites]. In the context of waste site assessments, stressors are chemical contaminations, and the contact and interaction are uptake of the contaminant by the receptor. Without sufficient exposure of the receptor to the contaminants, there is no ecological risk.

Unlike some other endpoint assemblages, terrestrial wildlife are significantly exposed to contaminants in multiple media. They may drink or swim in contaminated water, ingest contaminated food and soil, and breath contaminated air. In addition, because most wildlife are mobile, moving among and within habitats, exposure is not restricted to a single location. They may integrate contamination from several spatially discrete sources. Therefore, exposure models for terrestrial wildlife must include multiple media.

This document provides models and parameters for estimating exposure of birds and mammals. Reptiles and amphibians are not considered because few data exist with which to assess exposure to these organisms. In addition, because toxicological data are scarce for both classes, evaluation of the significance of exposure estimates is problematic. However, the general exposure estimation procedure developed herein for birds and mammals is applicable to reptiles and amphibians.

Exposure models must be appropriate to the assessment endpoints. The models presented herein are models of the exposure of individual organisms, but except for threatened and endangered species, all the wildlife endpoints for the ORR are for populations (Suter et al. 1994). The use of organism exposures is appropriate because of the need to integrate exposure estimates with exposure-response information which is expressed as organism-level responses. The conversion of individual exposure to population effects occurs in the risk characterization.

Conceptually, the conversion of organism-level exposures to the population level can be made in two ways. First, it may be assumed that there is a distinct population on the site so that the exposure of the population is the exposure of all the individuals. This assumption is appropriate for small organisms on large sites, particularly if the site constitutes a distinct habitat that is surrounded by inappropriate habitat. For example, a grassy site surrounded by forest or industrial development might support a distinct population of voles. The risks to that population can be estimated directly from the exposures of the individual organisms. Second, it may be assumed that a certain number of individuals are exposed to contaminants out of a larger population. For example, a certain proportion of a deer herd may forage on a site or a pair of hawks may hunt on a site. The estimated exposure of these individuals will result in estimation of certain effects on those individuals, and the resulting population risks will need to be characterized. In either case, the organism level exposure models are appropriate.

2. GENERALIZED EXPOSURE MODEL

As terrestrial wildlife move through the environment, they may be exposed to contamination via three pathways: oral, dermal, or inhalation. Oral exposure occurs through the consumption of contaminated food, water, or soil. Dermal exposure occurs when contaminants are absorbed directly through the skin. Inhalation exposure occurs when volatile compounds or fine particulates are respired into the lungs. The total exposure experienced by an individual is the sum exposure from all three pathways or:

$$E_{total} = E_{oral} + E_{dermal} + E_{inhal} \tag{1}$$

where:

E_{total} = exposure from all pathways
E_{oral} = oral exposure
E_{dermal} = dermal exposure
E_{inhal} = exposure through inhalation

Dermal exposure is assumed to be negligible for birds and mammals on most United States Department of Energy (DOE) waste sites. While methods are available to assess dermal exposure to humans (EPA 1992), data necessary to estimate dermal exposure are generally not available for wildlife (EPA 1993a). Additionally, many contaminants (e.g., metals and radionuclides) found on the ORR and other DOE facilities are unlikely to be absorbed through skin (Camner et al. 1979, Watters et al. 1980). Feathers and fur of birds and mammals further reduce the likelihood of significant dermal exposure by limiting the contact of skin with contaminated media. Therefore, dermal exposure is expected to be negligible relative to other routes in most cases and is not considered in the models presented in this report. If contaminants that have a high affinity for dermal uptake (e.g., organic solvents and pesticides) are present and an exposure scenario for an endpoint species is likely to result in significant dermal exposure (e.g., burrowing or swimming amphibians), then a research effort to quantify dermal exposure for those contaminants and species may be justified.

Inhalation of contaminants is also assumed to be negligible at the ORR and other DOE facilities for two reasons. (Therefore, the inhalation pathway is not considered in the models presented in this report.) First, because most contaminated sites are either capped or vegetated, exposure of contaminated surface soils to winds and resulting aerial suspension of contaminated dust particulates is minimized. Second, most volatile organic compounds (VOCs), the contaminants most likely to present a risk through inhalation exposure, rapidly volatilize from soil and surface water to air, where they are rapidly diluted and dispersed. Because of the age of the waste sites where VOCs were disposed of on the ORR and the short residence time of VOCs, significant exposure to volatile organic compounds through inhalation is unlikely. In situations where inhalation exposure of endpoint species is believed to be occurring or is expected to occur, methods to estimate the exposure and resulting risk should be developed.

Because contaminant exposure experienced by wildlife through both the dermal and inhalation pathways is negligible, the majority of exposure must be attributed to the oral exposure pathway. Equation 1 can therefore be simplified to:

$$E_{total} \approx E_{oral} \; . \qquad (2)$$

2.1 ORAL EXPOSURE MODEL

Oral exposure experienced by wildlife may come from multiple sources. They may consume contaminated food (either plant or animal), drink contaminated water, or ingest soil. Soil ingestion may be incidental while foraging or grooming or purposeful to meet nutrient needs. The total oral exposure experienced by an individual is the sum of the exposures attributable to each source and may be described as:

$$E_{total} \approx E_{oral} + E_{food} + E_{water} + E_{soil} \qquad (3)$$

where:

E_{total} = total exposure from all pathways
E_{oral} = total exposure from oral ingestion
E_{food} = exposure from food consumption
E_{water} = exposure from water consumption
E_{soil} = exposure from soil consumption

For exposure estimates to be useful in the assessment of risk to wildlife, they must be expressed in terms of a body weight-normalized daily dose or mg contaminant per kg body weight per day (mg/kg/d). Exposure estimates expressed in this manner may then be compared to toxicological benchmarks for wildlife, such as those derived by Opresko et al. (1994), or to doses reported in the toxicological literature. Estimation of the daily contaminant dose an individual may receive from a particular medium for a particular contaminant may be calculated using the following equation:

$$E_j = \sum_{i=1}^{m} \left(\frac{IR_i \text{ x } C_{ij}}{BW} \right) \qquad (4)$$

where:
E_j = total exposure to contaminant (j) (mg/kg/d)
m = total number of ingested media (e.g., food, water, or soil)
IR_i = consumption rate for medium (i) (kg/d or L/d)
C_{ij} = concentration contaminant (j) in medium (i) (mg/kg or mg/L)
BW = body weight of endpoint species (kg)

Note: Soil ingestion rates and soil contaminant concentrations are in kg dry weight. All other weights (body weights, food, etc.) are in kg fresh weight.

2.2 DIET COMPOSITION

Few wildlife species consume diets that consist exclusively of one food type. To meet nutrient needs for growth, maintenance, and reproduction, most wildlife consume varying amounts of multiple food types. Because it is unlikely that all food types consumed will contain the same contaminant concentrations, dietary diversity is of one of the most important exposure modifying factors.

To account for varying contaminant concentrations in different food types, exposure estimates should be weighted by the relative proportion of daily food consumption attributable to each food type and the contaminant concentration in each food type. This may be done by modifying Equation 4 as follows:

$$FE_j = \sum_{i=1}^{m} \left(\frac{FIR_i \ x \ C_{ij}}{BW} \right) \tag{5}$$

where:

C_{ij} = concentration of contaminant (j) in food type (i) (mg/kg, fresh weight)
FE_j = exposure to contaminant (j) attributed to food (mg/kg/d)
FIR_i = ingestion rate (kg/individual/day) for the i^{th} food type

The ingestion rate for each food type, FIR_i, may be estimated as follows:

$$FIR_i = P_i \ x \ FIR \tag{6}$$

where:

P_i = proportion of the i^{th} food type in the diet
FIR = total food ingestion rate (kg/individual/day)

2.3 HOME RANGE/HABITAT REQUIREMENTS

If the site is spatially heterogeneous with respect to either contamination or wildlife use, the model must be modified to include spatial factors. The most important spatial consideration is the movement of wildlife. Animals travel varying distances, on a daily to seasonal basis, to find food, water, and shelter. The area encompassed by these travels is defined as the home range. (The term is used herein to include territories. A territory is a subset of the home range that is actively defended to exclude other con-specific individuals.) If the site being assessed is larger than the home range of an endpoint species and provides the habitat needs of the species, then the previously listed models are adequate. However, endpoint species often have home ranges that are larger than contaminated sites, or the contaminated site may not supply all of a species habitat requirements. In those cases, the wildlife exposure model must be modified to account for the fraction of the home range potentially encompassed by suitable habitat at the site.

If the contaminated site has similar habitat quality to the surrounding area but is smaller than the home range, use of the contaminated site is simply a function of its area. That is, one can assume that exposure is proportional to the ratio of the size of the contaminated site to home range size and modify Equation 4 as follows:

$$E_j = \left(\frac{A}{HR}\left[\sum_{i=1}^{m}\left(\frac{IR_i \times C_{ij}}{BW}\right)\right]\right) \tag{7}$$

where:

A = area (ha) contaminated

HR = home range size (ha) of endpoint species

Note that *A* is the area contaminated, not the entire area that has been designated a waste site (e.g., an operable unit). Because boundaries are often drawn conservatively, they may contain a considerable uncontaminated area. However, because more detailed characterization of contaminant distribution is generally not available, assuming that the entire area is contaminated may be appropriate. To prevent grossly inflated estimates, in cases where the size of the contaminated area is greater than the organism's home range, A/HR should be set to 1.

The previous equation (7) implies that all the habitat within a contaminated area is suitable, and use of all portions of the contaminated area is equally likely. Because many waste sites are industrial or highly modified in nature, it is unlikely that all areas within their bounds will provide habitat suitable for endpoint species. If it is assumed that use of a waste site will be proportional to the amount of suitable habitat available on the site, Equation 7 may be modified to read:

$$E_j = P_h \left(\frac{A}{HR}\left[\sum_{i=1}^{m}\left(\frac{IR_i \times C_{ij}}{BW}\right)\right]\right) \tag{8}$$

where:

P_h = proportion of suitable habitat in the contaminated area.

One complication is the spatial heterogeneity of contaminants on waste sites. These models (Equations 4–8) are based on the assumption that either contaminants are evenly distributed on the site or that wildlife forage randomly with respect to contamination on the portion of the site which constitutes habitat so wildlife are exposed to mean concentrations. However, if contaminant levels are related to habitat quality, that assumption would not hold. For example, contaminant concentrations might be greatest near the center of a site, but the habitat quality might be highest near the edges. In such cases, it might be necessary to model the proportional contribution of each area with a distinct combination of contaminant level and habitat quality.

$$E_j = \sum_{k=1}^{n}\left(\frac{A_k}{HR}\left[\sum_{i=1}^{m}\left(\frac{IR_i \times C_{ijk}}{BW}\right)\right]\right) \tag{9}$$

where:

n = number of distinct contaminated habitat areas

A_k = area (ha) of a distinct contaminated habitat area
C_{ijk} = concentration of contaminant (j) in the ith medium type in the kth area (mg/kg or mg/L)

To model exposures of wide-ranging wildlife to multiple waste sites, as is planned for the ORR (Suter et al. 1994), Equation 9 should be modified to include multiple waste sites as follows:

$$E_j = \sum_{l=1}^{o} \sum_{k=1}^{n} \left(\frac{A_{kl}}{HR}\left[\sum_{i=1}^{m}\left(\frac{IR_i \ x \ C_{ijkl}}{BW}\right)\right]\right) \qquad (10)$$

where:
o = number of waste sites
A_{kl} = area (ha) of a distinct contaminated habitat area within each waste site
C_{ijkl} = concentration of contaminant (j) in the ith medium type in the kth habitat area of the lth waste site (mg/kg or mg/L)

If the distribution of contamination and habitat quality is complex, this approach becomes ungainly. In such cases, it is advisable to implement the exposure in a Geographic Information System (GIS). Using a GIS, maps displaying the spatial distribution of various habitat types may be overlaid with maps of contaminant distribution to accurately determine the degree to which habitat is contaminated. Furthermore, if information on the distribution or movements of wildlife (generated by radiotelemetry or censuses) are available, these data may be combined with the habitat and contamination data to provide a more accurate visualization of exposure.

2.4 OTHER FACTORS

Factors other than those described in these models modify contaminant exposure experienced by wildlife endpoint species. These factors include age, sex, season, and behavior patterns.

These models imply that the endpoint species have uniform body size, metabolism, diet, home ranges, and habitat requirements. However, these properties may differ between juveniles and adults, and males and females. For example, because they are actively growing, metabolism (and therefore the rate of food consumption) is generally greater for juveniles for most endpoint species. Similarly, the food requirements of females during reproduction are greater than that for males for many endpoint species. These factors may serve to make certain age classes or a particular sex experience greater contaminant exposure than other segments of the population. Because of their greater exposure, contamination may present a greater risk to these segments of the population. If it is known that a particular lifestage or sex is sensitive to contamination, that lifestage should be emphasized in the exposure assessment.

Behavior may modify exposure by increasing or decreasing the likelihood of contact with contaminated media. Wildlife behaviors are frequently seasonal in nature. Some foods may be available and consumed only at certain times of the year. Similarly, some habitats and certain parts of the home range may be used only in certain seasons. In addition, many species hibernate or migrate; by leaving the area or restricting their activity to certain times of year, their potential exposure may be dramatically reduced. All of these factors should be considered when evaluating contaminant exposure experienced by wildlife, and exposure models should be adjusted accordingly.

3. PARAMETERS FOR ESTIMATION OF EXPOSURE

Implementation of the exposure model presented in Equation 4 requires the specification of certain parameters. Some parameters, such as home range size, body weights (Sect. 3.1), and soil consumption rates (Sect. 3.3), must be obtained from the literature for the endpoint species, while others, such as area contaminated, are site-specific. General methods are available for estimating food and water consumption rates (Sects. 3.2 to 3.4).

3.1 BODY WEIGHT

Body weight is an important parameter in the estimation of exposure. Not only is it a factor in determining the exposure rate (see Equation 4), but because metabolism and body weight are related, body weights may be used to predict food and water consumption rates. On an individual basis, larger animals consume more food or water than do smaller animals. However, larger animals have lower metabolic rates than smaller animals because smaller bodies have higher food and water consumption rates per unit body weight. Therefore, smaller animals will experience greater oral exposure per unit body weight than will larger animals.

Body weights for selected terrestrial wildlife are reported by the United States Environmental Protection Agency (EPA) (1993a). Additional sources include Dunning (1984), Burt and Grossenheider (1976), and the Mammalian Species series, published by the American Society of Mammalogists.

3.2 FOOD AND WATER CONSUMPTION

Field observations of food, water, or soil consumption rates are the best data to use to estimate exposure. With few exceptions, these data are unavailable for wildlife species. The second best data to use to estimate exposure are media consumption rates for wildlife species derived from laboratory studies. These data are limited because the influence of ambient conditions, such as activity regimes or environmental variables (temperature, humidity, etc.), on metabolism (and therefore consumption rates) are difficult to approximate in a laboratory setting.

In the absence of experimental data, food consumption values can be estimated from allometric regression models based on metabolic rate. Nagy (1987) derived equations to estimate food consumption (in kg dry weight) for various groups of birds and mammals:

$$FIR = 0.0687(BW)^{0.822} \quad \text{(placental mammals)} \tag{11}$$

$$FIR = 0.0306(BW)^{0.564} \quad \text{(rodents)} \tag{12}$$

$$FIR = 0.0875(BW)^{0.727} \quad \text{(herbivores)} \tag{13}$$

$$FIR = 0.0514(BW)^{0.673} \quad \text{(marsupials)} \tag{14}$$

$$FIR = 0.0582(BW)^{0.651} \quad \text{(all birds)} \tag{15}$$

$$FIR = 0.141(BW)^{0.850} \quad \text{(passerine birds)} \tag{16}$$

Note: BW is in kg fresh or live weight.

Food ingestion rates estimated using these allometric equations are expressed as kg dry weight. Because wildlife do not generally consume dry food (unless being maintained in the laboratory), food consumption must be converted to kg fresh weight by adding the water content of the food. Percent water content of wildlife foods are listed in Table 1. Calculation of food consumption in kg fresh weight is performed as follows:

$$FIR_{fresh} = \sum_{i=1}^{f} (P_i \text{ x } \frac{FIR_{dry}}{1 - WC_i}) \tag{17}$$

where:

FIR_{fresh} = total food ingestion rate (kg food [fresh weight]/individual/day)

f = total number of food types in the diet

P_i = proportion of the i^{th} food type in the diet

WC_i = proportional water content (by weight) of the i^{th} food type

Table 1. Percent water content of wildlife foods[a]

Food Type	Percent Water Content		
	Mean	Standard Deviation	Range[b]
Aquatic Invertebrates			
bivalves (w/o shell)	82	4.5	
crabs (w/shell)	74	6.1	
shrimp	78	3.3	
isopods, amphipods			71-80
cladocerans			79-87
Aquatic Vertebrates			
bony fishes	75	5.1	
Pacific herring	68	3.9	
Aquatic Plants			
algae	84	4.7	
aquatic macrophytes	87	3.1	
emergent vegetation			45-80
Terrestrial Invertebrates			
earthworms (depurated)	84	1.7	
grasshoppers,crickets	69	5.6	
beetles (adult)	61	9.8	
Mammals			
mice, voles, rabbits	68	1.6	
Birds			
passerines (w/typical fat reserves)			68
mallard duck (flesh only)			67
Reptiles and Amphibians			
snakes, lizards			66
frogs,toads	85	4.7	
Terrestrial Plants			
monocots: young grass			70-88

Table 1. (continued)

Food Type	Percent Water Content		
	Mean	**Standard Deviation**	**Range**[b]
monocots: mature dry grass			7-10
dicots: leaves	85	3.5	
dicots: seeds	9.3	3.1	
fruit: pulp, skin	77	3.6	

[a] Derived from EPA 1993a

[b] Single values indicate only one value available.

Water consumption rates can also be estimated for mammals and birds from allometric regression models based on body weight (Calder and Braun 1983):

$$WIR = 0.099(BW)^{0.90} \quad \text{mammals} \tag{18}$$

$$WIR = 0.059(BW)^{0.67} \quad \text{birds} \tag{19}$$

where:

WIR = water ingestion rate (L water/individual/day).

Note: BW is in kg fresh or live weight.

3.3 SOIL CONSUMPTION

In addition to consuming food and water, many wildlife consume soil. Soil consumption may occur inadvertently while foraging (i.e., predators of soil invertebrates ingesting soil adhering to worms, grazing herbivores consuming soil deposited on foliage or adhering to roots, etc.) or grooming or purposefully to meet nutrient requirements because diets of many herbivores are deficient in sodium and other trace nutrients (Robbins 1993). For example, ungulates, such as white-tailed deer (*Odocoileus virginianus*), have been observed to consume soils with elevated sodium levels, presumably to meet sodium needs (Weeks 1978). Because soils at waste sites may contain high contaminant concentrations, direct ingestion of soil is potentially a significant exposure source. In contrast to food and water consumption, generalized models do not exist with which to estimate soil ingestion by wildlife. Beyer et al. (1994) reports soil consumption estimates for 28 wildlife species. Additional data concerning soil consumption are reported in Arthur and Alldredge (1979), Garten (1980), Thornton and Abrahams (1983), and Arthur and Gates (1988),

4. LIFE HISTORY PARAMETERS FOR SELECTED ENDPOINT SPECIES

To estimate contaminant exposure to terrestrial wildlife using the models described previously, species-specific values for the parameters are needed. Due to the large within-species variation in values for life-history parameters, data specific to the site in question would provide the most accurate exposure estimates. However, these data are virtually never available. Published values from other areas within an endpoint species range must therefore be used to estimate life-history parameters. Life-history parameters used in determining contaminant exposure are listed in the following tables for eight mammals and seven birds likely to be present on the ORR. These values were selected to be representative of each endpoint species, but it is recognized that some species display a high degree of variation for some parameters. Additional, more detailed data may be found in EPA (1993a) or obtained by searching the open literature if necessary.

4.1 SHORT-TAILED SHREW (*Blarina brevicauda*)

Parameter	Value[a]	Comments	Reference
Body Weight	**0.015** ± 0.00078 kg	New Hampshire (field)	Schlessinger and Potter 1974
Food Consumption Rate[b]	0.01 kg/d	larch sawfly diet (lab)	Buckner 1964
	0.00795 ± 0.00017 kg/d	mealworm diet (lab)	Barrett and Stueck 1976
	mean = **0.009** kg/d		
Water Consumption Rate	0.223 ml/g bw/d		Chew 1951
	0.0033 L/d	assuming a 0.015 kg bw	
Soil Consumption Rate[c]	13% of diet		Talmage and Walton 1993
	0.00117 kg/d	assuming diet of 0.009 kg/d	
Diet Composition	earthworms 31.4% slugs/snails 27.1% soil/litter invert 13.2% fungi 8.4% misc. animals 8.1% coleoptera 5.9% vegetation 5.4%	percent volume in diet in summer in New York	Whitaker and Ferraro 1963
Home Range	**0.39** ± 0.036 ha	Manitoba bog	Buckner 1966

Short-tailed Shrew (continued)

Parameter	Value[a]	Comments	Reference
Habitat Requirements	broad and variable but requires >50% herbaceous cover		Miller and Getz 1977
	forest, wetlands, and grasslands. Most abundant in hardwood forests with deep litter and humus.		van Zyll de Jong 1983
Population Density	2.3 /ha - winter 5.2 /ha - spring 9.3 /ha -summer 8.1 /ha - fall	Illinois - alfalfa, tallgrass, and bluegrass; means derived from graph.	Getz 1989
Behavior	nocturnal, semifossorial, spends little time above surface		George et al. 1986
	active year-round - does not hibernate		EPA 1993a
Other	appear to be unpalatable to most predators due to lateral gland		van Zyll de Jong 1983

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.2 LITTLE BROWN BAT (*Myotis lucifugus*)

Parameter	Value[a]	Comments	Reference
Body Weight	**0.0075** kg		Gould 1955
Food Consumption Rate[b]	**0.0025** kg/d	pregnant ♀ (field)	Anthony and Kunz 1977
	0.0037 kg/d	lactating ♀ (field)	
	0.0018 kg/d	juvenile (field)	
Water Consumption Rate	**0.0012** L/d	estimated using Equation 18; assuming 0.0075 kg bw	
Soil Consumption Rate[c]	as an aerial insectivore, assumed to be negligible		

Little Brown Bat (continued)

Parameter	Value[a]	Comments	Reference
Diet Composition	highly variable; mostly flying insects, taken opportunistically as available.		Fenton and Barclay 1980
	Chironomidae 39.5% Trichoptera 31.5% Lepidoptera 11.0% Misc. Insects 9.4% Coleoptera 5.5% Neuroptera 3.1%	percent volume in diet in Ontario, Nova Scotia, and New York	Belwood and Fenton 1976
Home Range	no data		
Habitat Requirements	day roosts: buildings, trees, occasionally in caves.		Fenton and Barclay 1980
	night roosts: similar to day roosts but more confined space		
	hibernation sites: caves, abandoned mines		
	foraging habitat: forest and edge	Missouri	LaVal et al. 1977
	Forest, field, and over streams and ponds	Ontario	Fenton and Bell 1979
Population Density	no data; however, populations may be limited by availability of roost sites, not by food		Fenton and Barclay 1980
Behavior	nocturnal; bimodal activity pattern: ~2200-2400 and ~0330-0500		Anthony and Kunz 1977
	hibernation September-May (north) November-March (south)		Fenton and Barclay 1980

Little Brown Bat (continued)

Parameter	Value[a]	Comments	Reference
Other	long-lived; may live up to 30 yrs. mean life expectancy: ♂ = 4.9 yrs ♀ = 2.9 yrs		Keen and Hitchcock, 1980

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.3 MEADOW VOLE (*Microtus pennsylvanicus*)

Parameter	Value[a]	Comments	Reference
Body Weight	**0.044** kg		Reich 1981
Food Consumption Rate[b]	**0.005** kg/d	estimated from figure (lab)	Dark et al. 1983
Water Consumption Rate	**0.006** L/d	estimated using Equation 18; assuming 0.044 kg bw	
Soil Consumption Rate[c]	2.4% of diet		Beyer et al. 1994
	0.00012 kg/d	assuming diet of 0.005 kg/d	
Diet Composition	herbivorous		
	predominantly monocot and dicot shoots; lesser amounts of seeds and roots (more in winter); minimal fungi and insects	Illinois bluegrass and prairie habitat	Lindroth and Batzli 1984
Home Range	**0.083** ± 0.037 ha ♂ **0.037** ± 0.020 ha ♀	Massachusetts - grassy meadow	Ostfeld et al. 1988
Habitat Requirements	grassy fields, marshes, and bogs		Getz 1961

Meadow Vole (continued)

Parameter	Value[a]	Comments	Reference
Population Density	28 - 85 /ha	Massachusetts - grassy meadow	Ostfeld et al. 1988
	~8 - ~20 /ha	Michigan - old field	Getz 1961
	2 - 28 /ha	Illinois bluegrass	Lindroth and Batzli 1984
	26 - 128 /ha	Illinois prairie	
Behavior	may be either diurnal or nocturnal; activity depends on amount of vegetative cover		Reich 1981
	active year-round—does not hibernate		EPA 1993a
Other	vole population decreases as short-tailed shrew numbers increase		Eadie 1952

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.4 WHITE-FOOTED MOUSE (*Peromyscus leucopus*)

Parameter	Value[a]	Comments	Reference
Body Weight	**0.022** kg		Green and Millar 1987
Food Consumption Rate[b]	**0.0034** kg/d	lab study	Green and Millar 1987
Water Consumption Rate	**0.0066** L/d	nonreproductive ♀ (lab)	Oswald et al. 1993
Soil Consumption Rate[c]	<2%		Beyer et al. 1994
	0.000068 kg/d	assuming diet of 0.0034 kg/d and a 2% soil consumption rate	

White-footed Mouse (continued)

Parameter	Value[a]	Comments	Reference
Diet Composition	omnivorous and opportunistic		
	arthropods—57% seeds, fruit, vegetation—34%	Virginia	Wolff et al. 1985
	arthropods—30% seeds, fruit, vegetation—67%	Indiana	Whitaker 1966
	arthropods—50% seeds, fruit, vegetation—48%	Illinois	Batzli 1977
Home Range	**0.059** ha	mean:♂+♀; Virginia, mixed deciduous forest	Wolff 1985
Habitat Requirements	wooded, brushy areas; sometimes open areas		Burt and Grossenheider 1976
Population Density	6 - 57 /ha	Virginia, mixed deciduous forest	Wolff 1985
Behavior	while semi-arboreal, spends most of time on ground.		Lackey et al. 1985
	primarily nocturnal		
	enters torpor to reduce metabolic demands in winter and during food stress		EPA 1993a

[a] Suggested values for use in exposure assessment are in bold.
[b] kg/d wet weight
[c] kg/d dry weight

4.5 EASTERN COTTONTAIL (*Sylvilagus floridanus*)

Parameter	Value[a]	Comments	Reference
Body Weight	1.134 kg (♂) 1.244 kg (♀) **1.2** kg (mean♂+♀)		Chapman et al. 1980
Food Consumption Rate[b]	**0.237** kg/d		Dalke and Sime 1941

Eastern Cottontail (continued)

Parameter	Value[a]	Comments	Reference
Water Consumption Rate	**0.116** L/d	estimated using Equation 18; assuming 1.2 kg bw	
Soil Consumption Rate[c]		assumed comparable to that for black-tailed jackrabbit (6.3% of diet)	Arthur and Gates 1988
	0.015 kg/d	assuming diet of 0.237 kg/d and a 6.3% soil consumption rate	
Diet Composition	exclusively herbivorous		
	bark, twigs, buds, dried herbs (fall, winter)		Dalke and Sime 1941
	herbaceous plants (spring, summer)		
Home Range	3.2 ha (♂); 2.1 ha (♀)	winter - Pennsylvania	Althoff and Storm 1989
	7.2 ha (♂); 2.8 ha (♀)	spring	
	7.8 ha (♂); 2.4 ha (♀)	summer	
	3.1 ha (♂); 1.5 ha (♀)	fall	
Habitat Requirements	wide variety of habitats used; old fields preferred		Chapman et al. 1980
Population Density	0.41 - 2.10 /ha (mean = 1.1/ ha)	Michigan	Eberhardt et al. 1963
Behavior	activity is greatest at dusk and dawn (crepuscular)		Chapman et al. 1980
	active year round - does not hibernate		EPA 1993a

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.6 MINK (*Mustela vison*)

Parameter	Value[a]	Comments	Reference
Body Weight	0.9 - 1.6 kg (♂) 0.7 - 1.1 kg (♀)		Linscombe et al. 1982
	1.0 kg (mean ♂+♀)		EPA 1993b Newell et al. 1987
Food Consumption Rate[b]	**0.137** kg/d (mean ♂+♀)		Bleavins and Aulerich 1981
Water Consumption Rate	**0.099** L/d	estimated using Equation 18; assuming 1.0 kg bw	
Soil Consumption Rate[c]	negligible	sand observed in 1.3% of mink scats; this amount did not account for any measurable scat volume.	Hamilton 1940
Diet Composition	Diverse diet includes: mammals ~ 46 % fish ~16 % aquatic invertebrates ~15% amphibians ~13 % and birds ~8 %	Percentages represent means of values from four studies	Hamilton 1940, Sealander 1943, Korschgen 1958, Burgess and Bider 1980
Home Range	2.63 km (♂) 1.85 km (♀)	stream - Sweden	Gerell 1970
	770 ha (♂)	prairie potholes, Manitoba	Arnold and Fritzell 1987
		range size and shape depends on habitat - linear along streams, circular in marshes	EPA 1993a
Habitat Requirements	aquatic habitats - streams, lakes, marshes;		Burt and Grossenheider 1976
Population Density	0.03 - 0.085 /ha	river - Montana	Mitchell 1961
Behavior	nocturnal active year-round, does not hibernate		EPA 1993a

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.7 RED FOX (*Vulpes vulpes*)

Parameter	Value[a]	Comments	Reference
Body Weight	5.25 ± 0.18 kg (♂) 4.13 ± 0.11 kg (♀)	Illinois	Storm et al. 1976
	4.82 ± 0.081 kg (♂) 3.94 ± 0.079 kg (♀)	Iowa	
	4.5 kg	mean ♂+♀ for both Illinois and Iowa	
Food Consumption Rate[c]	0.596 kg/d	see calculation below[b]	Vogtsberger and Barret 1973
	0.31 kg/d	0.069 g/g bw/d for nonbreeding adult times 4.5 kg bw	Sargeant 1978
	0.45 kg/d	mean of both estimates	
Water Consumption Rate	**0.38** L/d	estimated using Equation 18; assuming 4.5 kg bw	
Soil Consumption Rate[d]	2.8%		Beyer et al. 1994
	0.0126 kg/d	assuming diet of 0.45 kg/d	
Diet Composition	mammals - 68.8% birds - 12.0% plants - 10.4% insects - 0.9% misc. - 5.5%	Maryland, Appalachian region	
Home Range	699 ± 137 ha (♀ spring)	Minnesota - forest, field, swamp	Sargeant 1972
	717 ha (♂ all year) 96 ha (♀ all year)	Wisconsin - multiple habitats	Ables 1969
Habitat Requirements	wide and diverse - occur in many habitats		Voigt 1987
	prefer mixture of forest and open habitat		Burt and Grossenheider 1976
Population Density	0.046 - 0.077 /ha	"good fox range" in North America	EPA 1993a
Behavior	active year round - does not hibernate		EPA 1993a

[a] Suggested values for use in exposure assessment are in bold.

[b] The following parameters were presented by Vogtsberger and Barret (1973):

Red Fox (continued)

food ingestion = 223 kcal/kg bw/d
energy content of vertebrate food = 5.606 kcal/g dry wt.
wet-dry weight conversion = 1 g wet wt = 0.3 g dry wt

therefore:

223 kcal/kg bw/d x 4.5 kg bw = 1003.5 kcal/d

1003.5 kcal/d x 1g dry wt./5.606 kcal = 179 g dry/d

179 g dry/d x 1 g wet/0.3 g dry (wet-dry conversion) = 596 g/d

[c] kg/d wet weight
[d] kg/d dry weight

4.8 WHITE-TAILED DEER (*Odocoileus virginianus*)

Parameter	Value[a]	Comments	Reference
Body Weight	68 kg (♂) 45 kg (♀) **56.5** kg (mean♂+♀)		Smith 1991
Food Consumption Rate[b]	**1.74** kg/d		Mautz et al. 1976
Water Consumption Rate	**3.7** L/d	estimated using Equation 18; assuming 56.5 kg bw	
Soil Consumption Rate[c]	<2%		Beyer et al. 1994
	0.0348 kg/d	assuming 2% soil and 1.74 kg/d food consumption rates	
Diet Composition	exclusively herbivorous		
	diet diverse and variable, depends on availability.		Zim et al. 1951
	major foods: - buds and twigs of trees and shrubs - grasses and forbs (summer) - mast and fruits (fall)		Smith 1991
Home Range	59 - 520 ha		Marchinton and Hirth 1984

White-tailed Deer (continued)

Parameter	Value[a]	Comments	Reference
Habitat Requirements	uses a wide variety of habitats; favors forest-field-farmland mosaic; population density directly related to number and distribution of forest openings		Smith 1991
Population Density	0.06 /ha	eastern mixed deciduous forest - Tennessee	Barber 1984
	0.39 - 0.78 /ha	oak-hickory forest - midwest	Torgerson and Porath 1984
Behavior	generally crepuscular		Smith 1991
	active year-round; does not hibernate		

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.9 AMERICAN ROBIN (*Turdus migratorius*)

Parameter	Value[a]	Comments	Reference
Body Weight	**0.077** kg		Dunning 1984
Food Consumption Rate[b]	1.52 g/g bw/d or 117 g/d	assuming a 0.077 bw	Hazelton et al. 1984
	0.89 g/g bw/d or 68.5 g/d	assuming a 0.077 bw	Skorupa and Hothem 1985
	0.093 kg/d	mean of both values	
Water Consumption Rate	**0.0106** L/d	estimated using Equation 19; assuming 0.077 kg bw	

American Robin (continued)

Parameter	Value[a]	Comments	Reference
Soil Consumption Rate[c]		Assume that soil consumption is proportional to earthworm consumption. If the diet of woodcock is 99% earthworms and 10.4% of their diet is soil, then a robin consuming 20% earthworms will consume 2.08% soil.	Beyer et al. 1994
	0.0019 kg/d	assuming a diet of 0.093 kg/d	
Diet Composition	fruit - 7% invertebrates - 93%	percent volume; Eastern U.S. - spring	Wheelwright 1986
	fruit - 68% invertebrates - 32%	Eastern U.S. - summer	
	fruit - 92% invertebrates - 8%	Eastern U.S. - fall	
	fruit - 83% invertebrates - 17%	Eastern U.S. - winter	
	earthworms - 8.7-20%	summer	Heppner 1965
Home Range (territory)	0.42 ha	range: 0.12-0.84 ha Tennessee	Pitts 1984
Habitat Requirements	breeding: open woodlands, forest edge, fields, orchards foraging: grassy fields, orchards, lawns, gardens		DeGraaf and Rudis 1986
Population Density	2.3 pairs/ha	Tennessee	Pitts 1984
	4.7 - 6.2 pairs/ha	Wisconsin	Young 1951

American Robin (continued)

Parameter	Value[a]	Comments	Reference
Behavior	birds from the northern U.S. and Canada migrate and winter in the Gulf Coast and Carolinas.		National Geographic Society 1987
	permanent residents in southern portion of range		DeGraaf and Rudis 1986
Other	prefer foraging in short grass lawns as opposed to long grass. Mowing increases foraging activity		Eiserer 1980

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.10 AMERICAN WOODCOCK (*Scolopax minor*)

Parameter	Value[a]	Comments	Reference
Body Weight	0.176 kg (♂) 0.219 kg (♀)		Dunning 1984
	0.198 kg (mean♂+♀)		
Food Consumption Rate[b]	**0.15** kg/d		Sheldon 1971
Water Consumption Rate	**0.02** L/d	estimated using Equation 19; assuming 0.198 kg bw	
Soil Consumption Rate[c]	10.4%		Beyer et al. 1994
	0.0156 kg/d	assuming diet of 0.15 kg/d	
Diet Composition	primarily earthworms (58% - ~99%) plus other ground-dwelling invertebrates		Sperry 1940 Krohn 1970 Miller and Causey 1985 Stribling and Doerr 1985
Home Range	10.5 ha (singing ♂) 73.6 ha (active ♂) 3.1 ha (inactive ♂)	Pennsylvania - mixed forest fields	Hudgins et al. 1985

American Woodcock (continued)

Parameter	Value[a]	Comments	Reference
Habitat Requirements	breeding: moist early successional woodlands, swamps, river bottoms, alder thickets feeding: moist open pasture, cultivated fields, stream banks		DeGraaf and Rudis 1986
Population Density	3.4 /ha 0.2 /ha 0.034 /ha	winter—North Carolina untilled soy stubble untilled corn stubble rebedded corn	Connors and Doerr 1982
	0.21 nests/ha	mixed pine hardwoods—Pennsylvania	Coon et al. 1982
Behavior	migrate from northern breeding range to wintering range in south Atlantic and gulf coast states early migrants; leave wintering grounds in February, arrive at northern breeding grounds late March		Sheldon 1971

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.11 WILD TURKEY (*Meleagris gallopavo*)

Parameter	Value[a]	Comments	Reference
Body Weight	7.400 kg (♂) 4.222 kg (♀) **5.8** kg (mean♂+♀)		Dunning 1984
Food Consumption Rate[b]	13.6 g/lb bw/d		Korschgen 1967
	0.174 kg/d	assuming 5.8 kg bw	
Water Consumption Rate	**0.19** L/d	estimated using Equation 19; assuming 5.8 kg bw	

Wild Turkey (continued)

Parameter	Value[a]	Comments	Reference
Soil Consumption Rate[c]	9.3 %		Beyer et al. 1994
	0.0162 kg/d	assuming 0.174 kg/d food consumption rates	
Diet Composition	plant material (mast, fruit, seeds, some foliage) - 90.3% animal material (insects, crayfish, snails, salamanders) - 9.7 %		Korschgen 1967
Home Range	150 - 190 ha		DeGraaf and Rudis 1986
Habitat Requirements	mast-producing woodlands with associated fields and abundant water		DeGraaf and Rudis 1986
Population Density	0.03 /ha	West Virginia	DeGraaf and Rudis 1986
	0.06 - 0.076 /ha	in 'ideal' habitat	DeGraaf and Rudis 1986
Behavior	forage primarily on the ground roost in trees at night year-round resident; does not migrate		National Geographic Society 1987

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.12 BELTED KINGFISHER (*Ceryle alcyon*)

Parameter	Value[a]	Comments	Reference
Body Weight	**0.148** kg		Dunning 1984
Food Consumption Rate[b]	50% bw		Alexander 1977
	0.075 kg/d	assuming 0.148 kg bw	
Water Consumption Rate	**0.016** L/d	estimated using Equation 19; assuming 0.148 kg bw	

Belted Kingfisher (continued)

Parameter	Value[a]	Comments	Reference
Soil Consumption Rate[c]	as a piscivore, assumed to be negligible		
Diet Composition	Cyprinids - 76.4% other fish - 10.2% crayfish - 13.3%	creek—Ohio	Davis 1982
	lizards, small snakes, frogs, salamanders, and insects may be consumed if fish are unavailable		Landrum et al. 1993
Home Range	1.03 km (breeding) 0.39 km (non-breeding)	creek—Ohio	Davis 1982
	2.19 km (breeding)	stream summer—Pennsylvania	Brooks and Davis 1987
Habitat Requirements	use diverse aquatic habitats (stream, river, lake, marsh, coastline)		Brooks and Davis 1987
	require high vertical banks composed of >75% sand and <7% clay for nest construction		
	prefer relatively clear waters free of thick vegetation		Bent 1940
Population Density	0.11 - 0.19 pairs/km shore	stream summer—Pennsylvania	Brooks and Davis 1987
Behavior	while most migrate from northern parts of range, some may stay in areas where water remains ice-free		Bent 1940

[a] Suggested values for use in exposure assessment are in bold.
[b] kg/d wet weight
[c] kg/d dry weight

4.13 GREAT BLUE HERON (*Ardea herodias*)

Parameter	Value	Comments	Reference
Body Weight	2.576 kg (♂) 2.204 kg (♀) **2.39** kg (mean♂+♀)		Dunning 1984
Food Consumption Rate[b]	**0.42** kg/d	estimated using allometric equation[b] specific for herons and egrets assuming 5.8 kg bw	Kushlan 1978
Water Consumption Rate	**0.1058** L/d	estimated using Equation 19; assuming 2.39 kg bw	
Soil Consumption Rate[c]	as a piscivore, assumed to be negligible		
Diet Composition	diet predominantly fish but may include crustaceans, insects, snails, amphibians, reptiles, birds, and mammals		Kushlan 1978 Collazo 1985 Hoffman 1978
Home Range (foraging distance from colony)	3.1 km	up to 24.2 km-river—S. Dakota	EPA 1993a
	7 - 8 km	coastal—N. Carolina	Short and Cooper 1985
Habitat Requirements	use both coastal and inland water-associated habitats		Short and Cooper 1985
	foraging: shallow shores of ponds, lakes, streams, wet meadows, wooded swamps, bays, and marshes		DeGraaf and Rudis 1986
	breeding: trees for rookery sites. In absence of trees will use rock ledges, cliffs, and artificial structures		Short and Cooper 1985

Great Blue Heron (continued)

Parameter	Value	Comments	Reference
Population Density	nest colonially; therefore, population density depends on availability of nest habitat and suitable foraging habitat		EPA 1993a
Behavior	may or may not defend a feeding territory depending on local population size and food availability		Kushlan 1978
	Migrates in northern U.S. and southern Canada; year round resident from WV, PA south.		National Geographic Society 1987.

[a] Suggested values for use in exposure assessment are in bold.

[b] Allometric equation for estimation of food consumption by herons and egrets is:

$$\log FIR = 0.966 \log bw - 0.640$$

where:
FIR = food ingestion rate (g/d wet weight)
bw = body weight (g)

[c] kg/d wet weight

[d] kg/d dry weight

4.14 BARN OWL (*Tyto alba*)

Parameter	Value[a]	Comments	Reference
Body Weight	0.442 kg (♂) 0.490 kg (♀) **0.466** kg (mean♂+♀)		Dunning 1984
Food Consumption Rate[b]	0.1 - 0.15 kg/d **0.125** kg/d (mean)		Johnsgard 1988
Water Consumption Rate	**0.035** L/d	estimated using Equation 19; assuming 0.466 kg bw	

Barn Owl (continued)

Parameter	Value[a]	Comments	Reference
Soil Consumption Rate[c]	while some soil attached to prey may be ingested, amount is assumed to negligible		
Diet Composition	predominantly small mammals (*Microtus, Blarina, Peromyscus*, etc.) 80-90%; occasionally birds, amphibians, reptiles, and insects.		Johnsgard 1988 DeGraaf and Rudis 1986
	mean prey size: 27 - 123 g		Knight and Jackman 1984
Home Range	~250 ha		Johnsgard 1988
Habitat Requirements	feeding: marshes, meadows, fields, barnyards, brushy areas that attract rodents. Generally avoids woodlands. breeding: old buildings, trees, cliffs, quarries.		DeGraaf and Rudis 1986
Population Density	uncommon to rare		DeGraaf and Rudis 1986
Behavior	nocturnal, roosts during day, hunts at night.		DeGraaf and Rudis 1986
	except for extreme northern range, does not migrate		National Geographic Society 1987

[a] Suggested values for use in exposure assessment are in bold.

[b] kg/d wet weight

[c] kg/d dry weight

4.15 RED-TAILED HAWK (*Buteo jamaicensis*)

Parameter	Value[a]	Comments	Reference
Body Weight	1.028 kg (♂) 1.224 kg (♀) **1.126** kg (mean♂+♀)		Dunning 1984

Red-tailed Hawk (continued)

Parameter	Value[a]	Comments	Reference
Food Consumption Rate[b]	0.117 kg/d 0.136 kg/d 0.073 kg/d	(♂, fall/winter) (♀, fall/winter) (♂, spring/summer)	Craighead and Craighead 1969
	0.109 kg/d	(mean ♀ and ♂, all year)	
Water Consumption Rate	0.064 L/d	estimated using Equation 19; assuming 1.126 kg bw	
Soil Consumption Rate[c]	while some soil attached to prey may be ingested, amount is assumed negligible		
Diet Composition	predominantly small mammals		DeGraaf and Rudis 1986
	small mammal - 78.5% bird - 8.5% snake - 13.0%	Oregon - pasture and wheat fields	Janes 1984
	mammals: 13.2-18.7% birds: 78.6-80.1%	Montana, during nesting period	Craighead and Craighead 1969
Home Range	**233 ha**	pasture and wheat fields—Oregon	Janes 1984
	1936 ha (957 - 2465 ha range)	prairie-pinyon/juniper woodland—Colorado; mean of 4 birds; 95% ellipse and systematic relocation	Andersen and Rongstad 1989
Habitat Requirements	use wide range of habitats, prefer landscapes containing mixture of old fields, wetlands, and pasture for foraging interspersed with trees for perching and nesting		EPA 1993a DeGraaf and Rudis 1986
Population Density	0.03 - >0.005 pairs/ha		EPA 1993a

Red-tailed Hawk (continued)

Parameter	Value[a]	Comments	Reference
Behavior	territorial throughout year		EPA 1993a
	northerly populations migrate; those in the south do not		National Geographic Society 1987

[a] Suggested values for use in exposure assessment are in bold.
[b] kg/d wet weight
[c] kg/d dry weight

5. APPLICATION OF THE MODELS

To provide an example of the application of the models described in Sects. 2 and 3, contaminant exposure to wildlife was estimated using data from the Filled Coal Ash Pond (FCAP), a source operable unit on the ORR. Exposure was estimated for the meadow vole, red fox, white-tailed deer, and red-tailed hawk and compared to toxicological benchmarks obtained from Opresko et al. (1994).

5.1 SITE DESCRIPTION

The FCAP is a flat, 3.6-ha area located in the McCoy Branch watershed on the south slope of Chestnut Ridge, 0.8 km south of the Y-12 Plant. The site was constructed by building a 19-m high earthen dam across Upper McCoy Branch. The FCAP was built in 1955 to serve as a settling basin for coal ash from the Y-12 steam plant and continued to receive ash until 1989. Approximately 1–18 m of ash has accumulated behind the dam.

Vegetation has become established on the FCAP and grows directly in the coal ash. The difference in water level in the ash has resulted in two distinct vegetative zones. The lower one-third of the area is vegetated by hardwood trees with a dense understory. The upper portion of the FCAP has a higher water table and is vegetated by willows, sedges, and grasses. Small wetland areas with associated ponds occur in the northeast and northwest corners of the FCAP. Fish do not dwell in the ponds. Field observations, in addition to comparison of habitat requirements to habitat available on the FCAP, suggest that meadow vole, red fox, white-tailed deer, and red-tailed hawk make use of the site.

5.2 DATA

The following data were available to estimate contaminant exposure to wildlife: concentrations of arsenic, cadmium, chromium, lead, mercury, selenium, and thallium in coal ash, surface water, small mammals, and vegetation from the FCAP. In this example, actual measured values of contaminant residues were available for both abiotic media (ash and water) and some biota (plants and small mammals). In many instances, however, available data are likely to be restricted to contaminant concentrations in abiotic media. This frequently occurs with screening-level ecological risk assessments because they rely on existing data (which often consists only of concentrations in abiotic media).

Because contaminant concentrations in plant and animal wildlife foods are needed to fully estimate contaminant exposure for wildlife, if these data are not available, they must be generated from existing abiotic data. This may be done by using uptake factors that describe the relationship between contaminant concentrations in soil or water and that in biota. By multiplying the contaminant concentration in abiotic media by the appropriate uptake factor, concentrations in biota may be estimated.

Soil-plant uptake factors, for both reproductive and vegetative plant parts, were developed for inorganic contaminants (e.g., metals, radionuclides, etc.) by Baes et al. (1984). Travis and Arms (1988) report that uptake factors for organic chemicals in vegetation are inversely proportional to the square-root of the octanol-water partitioning coefficient (K_{ow}). Uptake of organics by earthworms may be estimated according to the method of Menzie et al. (1992) where:

$$UF = (Y_L)/(0.66 * f_{oc})$$

where:

UF = uptake factor

Y_L = earthworm lipid content

f_{oc} = organic carbon content of soil

Gish and Hughes (1982) report that the mean lipid content of earthworms is 0.84%. However, soil organic carbon content must be measured on a site-by-site basis. Values to estimate uptake of metals by earthworms may be obtained from the published literature such as Beyer and Stafford (1993).

After data have been obtained, a decision must be made as to which value to use to estimate exposure. Exposure may be estimated using several values to represent contaminant concentrations in media: the mean, upper 95% confidence interval on the mean (95% UCL), or the maximum value. To be conservative, risk assessments generally use either the 95% UCL or the maximum value. For sedentary species (e.g., plants, benthic invertebrates) that will be exposed at only one location, the maximum value is the most appropriate value to use. Because wildlife are mobile, they may be exposed to contamination from multiple locations within a site. Therefore, the most appropriate value to use for wildlife is the 95% UCL.

5.3 EXPOSURE ESTIMATION AND EVALUATION

Exposure estimates were calculated using data from the FCAP. Assumptions used in the estimates are outlined and the significance of the results are evaluated in the following text.

5.3.1 Meadow Vole

Estimates of contaminant exposure experienced by meadow voles were made using Equation 4 and the following assumptions.

1) body weight = 0.044 kg
2) ash consumption rate = soil consumption rate = 0.00012 kg/d
3) water consumption rate = 0.006 L/d
4) food consumption rate = 0.005 kg/d
5) contaminant concentrations measured in vegetation from the FCAP is representative of that in plants (and plant parts) consumed by meadow voles
6) because the home range of voles (0.037 - 0.083 ha) is smaller than the size of the FCAP (3.6 ha), 100% of food, water, and ash consumed was obtained from the FCAP.

Table 2 presents contaminant concentrations and exposure estimates for the meadow vole. Contaminant concentrations in ash are in mg/kg dry weight while that in food is in mg/kg wet weight.

To determine which contaminants are at potential hazardous concentrations, total exposure estimates should be compared to no observed adverse effects levels (NOAELs) for each contaminant. Estimated exposures to arsenic and selenium exceed NOAELs (Table 2); therefore, these contaminants may be adversely affecting meadow voles at the FCAP.

Contribution of each medium to total contaminant exposure helps to direct remedial actions and may be determined by dividing total exposure by the exposure estimate for each medium. For meadow voles on the FCAP, with the exception of arsenic, 70% to 100% of contaminant exposure is from food, and 0% to 30% is from incidental ash ingestion (Table 2). Water accounted for less than 1% of exposure. For arsenic, ash contributed 64% and food 36% of total exposure.

5.3.2 Red Fox

Estimates of contaminant exposure experienced by red fox were made using Equations 5, 6, and 7 and the following assumptions.

1) body weight = 4.5 kg
2) ash consumption rate = soil consumption rate = 0.0126 kg/d
3) water consumption rate = 0.38 L/d
4) food consumption rate = 0.45 kg/d
5) proportion of plant material in the diet = 0.104
6) contaminant concentrations measured in vegetation from the FCAP are representative of that in plants (and plant parts) consumed by red fox
7) proportion of mammals in the diet = 0.688
8) contaminant concentrations measured in small mammals from the FCAP are representative of that in small mammals consumed by red fox
9) no other foods consumed by red fox are contaminated
10) home range size for red fox = 96 ha
11) use of the FCAP and therefore consumption of food, water, or ash from the FCAP is proportional to the size of the FCAP (3.6 ha) in relation to the home range size for red fox (96 ha) or 0.0375 ha

Table 3 presents contaminant concentrations and exposure estimates for red fox. Contaminant concentrations in ash are in mg/kg dry weight while that in food is in mg/kg wet weight.

Comparison of the total exposure estimates to NOAELs for each contaminant indicate that exposure to selenium exceeds the NOAEL. Medium contributions to total contaminant exposure were similar to that for meadow voles; except for arsenic, most exposure was from food, followed by ash (Table 4). Water contributed little exposure.

5.3.3 White-tailed Deer

Estimates of contaminant exposure experienced by white-tailed deer were made using Equation 7 and the following assumptions.

1) body weight = 56.5 kg
2) ash consumption rate = soil consumption rate = 0.0348 kg/d
3) water consumption rate = 3.7 L/d
4) food consumption rate = 1.74 kg/d
5) contaminant concentrations measured in vegetation from the FCAP are representative of that in plants (and plant parts) consumed by white-tailed deer
6) to be conservative, the smallest reported home range was used. Therefore, home range size for white-tailed deer = 59 ha
7) use of the FCAP and therefore consumption of food, water, or ash from the FCAP is proportional to the size of the FCAP (3.6 ha) in relation to the home range size for white-tailed deer (59 ha) or 0.061

Table 5 presents contaminant concentrations and exposure estimates for white-tailed deer. Contaminant concentrations in ash are in mg/kg dry weight while that in food is in mg/kg wet weight.

Comparison of the total exposure estimates to NOAELs for each contaminant indicate that only selenium exceeds its NOAEL and almost all exposure (~98.8%) is attributable to plant consumption (Table 5).

In addition to being exposed to contaminants in ash through incidental consumption, white-tailed deer may be exposed by consuming ash to meet mineral needs. As discussed previously, because most plant material contains little sodium (Robbins 1993), the diet of many herbivores, including white-tailed deer, is often sodium deficient. To compensate for this sodium deficiency, many ungulates locate and consume soils rich in sodium (Weeks 1978). Coal ash on the FCAP is rich in sodium relative to background soils, and areas where white-tailed deer appear to have consumed ash have been observed at the FCAP.

Pletscher (1987) estimates that white-tailed deer require 301 mg Na/d of which only 23 mg Na/d is provided in their diet. This leaves a sodium deficit of 278 mg Na/d to be made up from other sources. An exposure estimate was calculated in which it was estimated that a deer would consume the amount of ash sufficient to eliminate the sodium deficit. To estimate the amount of ash consumed, it was assumed that deer would locate and consume ash from the most sodium-rich areas, therefore the maximum observed concentration of sodium (1080 mg/kg) was used to represent sodium concentrations in ash.

In the previous exposure estimate, use (and therefore exposure) of the FCAP was assumed to be proportional to the size of the FCAP relative to the size of the home range. In this case, because the FCAP may represent the only available sodium source in the area, it was assumed that deer travel to the site specifically to consume ash and that ash sufficient to satisfy 100% of the sodium deficit was consumed at the site. Ash consumption was estimated to be (278 mg Na/d)/(1080 mg Na/kg ash) = 0.257 kg ash/d. Exposure estimates for consumption of ash by deer to meet sodium requirements are displayed in Table 6. Exposure to three contaminants (arsenic, selenium, and thallium) were from 10 to almost 60 times greater than NOAELs (Table 6), indicating that ash consumption to meet sodium needs may result in adverse effects to white-tailed deer at the FCAP.

5.3.4 Red-tailed Hawk

Estimates of contaminant exposure experienced by red-tailed hawk were made using Equation 7 and the following assumptions.

1) body weight = 1.126 kg
2) ash consumption rate = soil consumption rate = 0 kg/d
3) water consumption rate = 0.064 L/d
4) food consumption rate = 0.91 kg/d
5) proportion of mammals in the diet = 0.785
6) contaminant concentrations measured in small mammals from the FCAP are representative of that in small mammals consumed by red-tailed hawks
7) no other food consumed by red-tailed hawks is contaminated
8) to be conservative, the smallest reported home range was used. Therefore, home range size for red-tailed hawk = 233 ha
9) use of the FCAP and therefore consumption of food or water from the FCAP is proportional to the size of the FCAP (3.6 ha) red-tailed hawk relative to home range size (233 ha) or 0.0155 ha

Table 7 presents contaminant concentrations and exposure estimates. Contaminant concentrations in ash are in mg/kg dry weight while that in food is in mg/kg wet weight.

Comparison of the total exposure estimates to NOAELs for each contaminant indicate that no contaminant exceeded NOAELs (Table 7). Because ash consumption was assumed to be negligible, virtually all exposure was obtained through food.

Table 2. Estimation of contaminant exposure for meadow voles using the FCAP

Contaminant	Contaminant Concentration in Media (upper 95% confidence interval)			Exposure Estimates[a] (mg/kg/d)				NOAELs for Meadow Voles[b] (mg/kg/d)	Percent of Total Exposure Attributed to Medium		
	Water (mg/L)	Ash (mg/kg)	Vegetation (mg/kg)	Water	Ash	Food	Total		Water	Ash	Food
Arsenic	0.01	131.00	1.77	0.00136	0.35727	0.20114	0.55977	0.111	0.24	63.82	35.93
Cadmium	nd[c]	nd	1.23	0	0	0.13977	0.13977	0.169	0	0	100
Chromium	0.0088	25.10	5.30	0.0012	0.06845	0.60227	0.67192	5425	0.18	10.19	89.63
Lead	0.0035	18.80	1.07	0.00048	0.05127	0.12159	0.17334	15.86	0.28	29.58	70.15
Mercury	nd	0.705	0.06	0	0.00192	0.00682	0.00874	0.063	0	21.97	78.03
Selenium	nd	14.80	23.61	0	0.04036	2.68295	2.72331	0.066	0	1.48	98.52
Thallium	nd	2.21	1.00	0	0.00603	0.11364	0.11967	0.015	0	5.04	94.96

[a] Calculated using Equation 4.

[b] From Opresko et al. 1994

[c] No data

Table 3. Estimation of contaminant exposure for red fox using the FCAP

	Contaminant Concentration in Media (upper 95% confidence interval)				Exposure Estimates[a] (mg/kg/d)					NOAELs for Red Fox[b] (mg/kg/d)
Contaminant	Water (mg/L)	Ash (mg/kg)	Mammals (mg/kg)	Plant (mg/kg)	Water	Soil	Food (Mammal)	Food (Plant)	Total	
Arsenic	0.01	131.00	0.219	1.77	0.000032	0.013755	0.000565	0.00069	0.01504	0.024
Cadmium	nd[c]	nd	0.033	1.23	0	0	0.000085	0.00048	0.00056	0.037
Chromium	0.0088	25.10	1.528	5.30	0.000028	0.002636	0.003942	0.002067	0.00867	1178
Lead	0.0035	18.80	2.861	1.07	0.000011	0.001974	0.007381	0.000417	0.00978	3.444
Mercury	nd	0.705	0.054	0.06	0	0.000074	0.000139	0.000023	0.00024	0.009
Selenium	nd	14.80	3.191	23.61	0	0.001554	0.008233	0.009208	0.01899	0.014
Thallium	nd	2.21	0.211	1.00	0	0.000232	0.000544	0.00039	0.00117	0.003

[a] Calculated using Equations 14, 15, and 16 .

[b] From Opresko et al. 1994

[c] No data

Table 4. Percent of total exposure attributed to medium for red fox using the FCAP

Contaminant	Water	Ash	Food (Mammal)	Food (Plant)
Arsenic	0.21	91.63	3.76	4.6
Cadmium	0	0	14.25	80.29
Chromium	0.32	30.42	45.5	23.86
Lead	0.11	20.18	75.44	4.26
Mercury	0	33.03	62.17	10.43
Selenium	0	8.19	43.4	48.54
Thallium	0	19.42	45.56	32.64

Table 5. Estimation of contaminant exposure for white-tailed deer using the FCAP

	Contaminant Concentration in Media (upper 95% confidence interval)			Exposure Estimates[a] (mg/kg/d)				NOAELs for White-tailed Deer[b] (mg/kg/d)	Percent of Total Exposure Attributed to Medium		
Contaminant	Water (mg/L)	Ash (mg/kg)	Vegetation (mg/kg)	Water	Ash	Food	Total		Water	Ash	Food
Arsenic	0.01	131.00	1.77	0.00004	0.004923	0.003326	0.00829	0.01	0.48	59.39	40.12
Cadmium	nd[c]	nd	1.23	0	0	0.002311	0.00231	0.016	0	0	100
Chromium	0.0088	25.10	5.30	0.000035	0.000943	0.009959	0.01094	511	0.32	8.62	91.04
Lead	0.0035	18.80	1.07	0.000014	0.000707	0.002011	0.00273	1.494	0.51	25.88	73.65
Mercury	nd	0.705	0.06	0	0.000027	0.000113	0.00014	0.006	0	18.93	80.54
Selenium	nd	14.80	23.61	0	0.000556	0.044366	0.04492	0.006	0	1.24	98.77
Thallium	nd	2.21	1.00	0	0.000083	0.001879	0.00196	0.001	0	4.24	95.87

[a] Calculated using Equation 7.

[b] From Opresko et al. 1994

[c] No data

Table 6. Estimation of Contaminant Exposure for white-tailed deer consuming ash from the FCAP to meet sodium needs

Contaminant	Contaminant Concentration in Ash (mg/kg)	Exposure Estimates[a] (mg/kg/d)	NOAELs for White-tailed Deer[b] (mg/kg/d)	Hazard Quotient (exposure/NOAEL)
Arsenic	131.00	0.595876	0.01	59.6
Cadmium	nd[c]	0	0.016	0
Chromium	25.10	0.114172	511	0.00022
Lead	18.80	0.085515	1.494	0.06
Mercury	0.705	0.003207	0.006	0.54
Selenium	14.80	0.06732	0.006	11.22
Thallium	2.21	0.010053	0.001	10.05

[a] Calculated using Equation 4.

[b] From Opresko et al. 1994

[c] No data

Table 7. Estimation of contaminant exposure for red-tailed hawks using the FCAP

Contaminant	Contaminant Concentration in Media (upper 95% confidence interval)			Exposure Estimates[a] (mg/kg/d)				NOAELs for Red-tailed Hawk[b] (mg/kg/d)	Percent of Total Exposure Attributed to Medium		
	Water (mg/L)	Ash (mg/kg)	Mammal (mg/kg)	Water	Ash	Food (Mammal)	Total		Water	Ash	Food (Mammal)
Arsenic	0.01	131.00	0.219	0.000009	0	0.000257	0.00027	4.938	3.25	0	95.23
Cadmium	nd[c]	nd	0.033	0	0	0.000039	0.00004	1.461	0	0	96.88
Chromium	0.0088	25.10	1.528	0.000008	0	0.001794	0.0018	1.035	0.43	0	99.67
Lead	0.0035	18.80	2.861	0.000003	0	0.003359	0.00336	1.888	0.09	0	99.97
Mercury	nd	0.705	0.054	0	0	0.000063	0.00006	0.006	0	0	105.67
Selenium	nd	14.80	3.191	0	0	0.003747	0.00375	0.481	0	0	99.91
Thallium	nd	2.21	0.211	0	0	0.000248	0.00025	nd	0	0	99.09

[a] Calculated using Equation 16.

[b] From Opresko et al. 1994

[c] No data

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