# ECOLOGICAL EXPOSURE MODULE

# BACKGROUND AND IMPLEMENTATION IN MULTIMEDIA, MULTIPLE EXPOSURE PATHWAY AND MULTIPLE RECEPTOR RISK ASSESSMENT (3MRA) FOR HWIR99


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Mr. Stephen Beaulieu and Mr. Abdul Tohmaz of Research Triangle Institute developed the ecological exposure module. Ms. Miriam Gilkinson and Ms. Jennifer Drake of Research Triangle Institute, tested and implemented the current version of the model.

## DISCLAIMER

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# 1.0 Module Overview and Summary of Functionality

## 1.1 Overview

The Ecological Exposure (EcoEx) module calculates the applied dose (in mg/kg-d) to ecological receptors that are exposed to contaminants via ingestion of contaminated plants, prey, and media (i.e., soil, sediment, and surface water). These dose estimates are then used as inputs to the Ecological Risk module. The EcoEx module calculates exposures for each receptor home range placed within a terrestrial or freshwater aquatic habitat (as defined in the site layout). Thus, exposure is a function of: (1) the home range (or portion, thereof) to which the receptor is assigned; (2) the spatial boundaries of the home range, (3) the food items (plants and prey) that are available in a particular home range, (4) the dietary preferences for food items that are available, and the media concentrations in the receptor's home range. In essence, the module estimates an applied dose for birds, mammals, and selected herpetofauna that reflects the spatial and temporal characteristics of the exposure (i.e., exposure is tracked through time and space).

The conceptual approach in developing the ecological exposure assessment for HWIR was to reflect the major sources of variability in ecological exposures (including the EcoEx module and supporting databases). In particular, the approach considers variability through: (1) the development of representative habitats; (2) selection of receptors based on ecological region; (3) the recognition of opportunistic feeding and foraging behavior using probabilistic methods; (4) the creation of a dietary scheme specific to region, habitat, and receptor; and (5) the application of appropriate graphical tools to capture spatial variability in exposure. The underlying framework for the EcoEx module is based on a representative habitat scheme to increase the resolution of general terrestrial and freshwater systems. The spatial characteristics of the site-based database were determined using a geographic information system (GIS) delineation tool to define habitat boundaries and linkages, home ranges, wetlands areas, and surface waterbodies. A cross-referencing database was developed to automate the selection of receptors and assign them to habitats based on habitat characteristics and ecological region. A complete description of the habitats, home ranges, receptors, and delineation scheme implemented in the GIS format is found in the documentation of data collection activities, Section 13 - Ecological Receptors and Habitats.

Depending on the type of habitat and chemical-specific uptake and accumulation, animals may be exposed through the ingestion of plants (both aquatic and terrestrial), soil invertebrates, aquatic invertebrates, fish, terrestrial vertebrates, media, or any combination that is reflected by the dietary preferences of the particular species. For example, an omnivorous animal that inhabits a freshwater stream habitat may ingest fish, small terrestrial vertebrates found in the stream corridor, terrestrial and aquatic plants, surface water, and soil. The dietary preferences are independent of the chemical type and, therefore, contaminant concentrations in some food items may be near zero for chemicals that do not bioaccumulate. The dietary preferences for each receptor are supported by an extensive exposure factors database containing information on, for example, dietary habits and natural history for over 50 representative species of interest. The module includes an innovative approach to characterizing the diet: a probabilistic algorithm that cycles through the database on minimum and maximum prey preferences to simulate dietary variability.

The concentration inputs required by the EcoEx module are provided by the Terrestrial Food Web module (TerFW), the Aquatic Food Web module (AqFW), the Surface Water Module (SW), and the Surface Impoundment module (a common source output file). These inputs are described in detail in Appendix A and include:

*Terrestrial Food Web*

- Spatially averaged surficial soil concentration by home range
- Spatially averaged concentration in soil invertebrates by home range
- Spatially averaged concentration in various plant types by home range
- Minimum and maximum concentrations in various categories of vertebrates across the habitat (e.g., small mammals, small birds, omnivores)

*Aquatic Food Web*

- Average, reach-specific concentration in aquatic (water column) invertebrates
- Average, reach-specific concentration in benthic invertebrates
- Average, reach-specific concentration in aquatic macrophytes
- Average, reach-specific concentration in trophic level 3 (T3) fish
- Average, reach-specific concentration in trophic level 4 (T4) fish

*Surface Water*

- Average, reach-specific concentration in sediment
- Average, reach-specific concentration in surface water

*Surface Impoundment*

- Average concentration in surface impoundment water

## 1.2 Summary of Functionality

The major computational functions performed by the Ecological Exposure module can be summarized as follows:

- # *Time series management*. The EcoEx module determines the overall duration of the time period to be simulated (including concentration data from discontinuous time periods) and identifies the individual years within the overall duration that will be simulated.

- # *Module loops over the time series, through habitats and receptors.* The EcoEx module has three basic loops: (1) over the time series, (2) over each habitat delineated at the site, and (3) over the mammalian, avian, and selected herpetofauna receptors assigned to each habitat.

- # *Calculation of time series exposures from time series media and food concentrations.* This is the fundamental structure of the EcoEx module, namely, to develop exposure concentrations for each year of the simulation that include all relevant receptors, food items, and media. These exposure concentrations are spatially explicit with regard to the home range for each ecological receptor.

The major calculation steps performed by the Ecological Exposure module that are required to calculate an applied dose may be summarized as follows:

- # Select receptor of interest.
- # Get media concentrations from TerFW module, SW module, and SR module.
- # Calculate average media concentrations to which receptor is exposed.
- # Construct diet for receptor of interest (i.e., composition and preferences).
- # Get plant and prey concentrations for dietary items from TerFW.
- # Sum intake from media and food sources.
- # Calculate potential applied dose by adjusting for body weight.
- # Calculate applied dose by prorating dose by habitat / home range ratio.

The calculation of time series exposures is described in detail in Section 3.0.

# 2.0 Assumptions and Limitations

The exposure characterization methodology used in the Ecological Exposure Module reflects a number of assumptions and/or limitations, which are listed below.

## 2.1 Assumptions

- *Study area is bounded at 2 km.* EPA assumed that significant exposures to source-related contaminants do not occur for ecological receptors that are beyond 2 km of the source. Consequently, exposures are not evaluated for receptors outside of the study area, measured from the edge of the source to a point 2 km away.

- *All areas delineated as habitat support wildlife.* EPA assumed that habitats delineated at each site are capable of sustaining a variety of wildlife. Because the predator-prey interactions for each habitat are represented by a simple food web, we assumed each habitat to be of sufficient quality to support multiple trophic levels and at least one reproducing pair of upper trophic level predators. Hence, exposure estimates reflect essentially free access to any of the food items suggested in the database on ecological exposure factors.

- *There are no other chemical stressors in the study area.* Because this is a site-based (rather than site-specific) assessment we assumed that ecological receptors were not subjected to other stressors within the study area. Background concentrations of constituents were not considered in developing exposure estimates, nor were other potential nonchemical stressors such as habitat fragmentation.

- *No less than 10 percent of the diet is attributed to the study area.* In many instances, the home range for a given receptor exceeds the size of the habitat. In general we assumed that the percent of the home range that "fits" into the habitat is a suitable surrogate with which to scale exposures. However, the purpose of this analysis is to determine acceptable waste concentrations assuming that suitable portions of the study area (e.g., forests) would be used as habitat by wildlife. Therefore, we assumed that no less than 10 percent of the diet originated from the study area, even if the fraction of the home range inside the habitat fell below 10 percent.

- # *Spatial averaging of exposures is defined by habitat and home range.* For this site-based assessment of representative habitats, we assumed that a reasonable approach to define the spatial extent of exposure for each receptor was to place the home range within the habitat boundaries. If the home range was larger than the habitat (i.e., extends beyond AOI) the exposure was averaged across the habitat and then prorated. However, alternative approaches were considered, including the calculation of exposure point concentrations based on a random walk across various habitats.

## 2.2 Limitations

- # *Plant categories were defined by analogy.* Vegetation categories relevant to wildlife were extrapolated from the plant categories defined for use in the Farm Food Chain (FFC) module. The cross reference for vegetative categories consumed by wildlife is presented in the Terrestrial Food Web module documentation.

- # *Annual average concentrations define exposure.* The exposure profiles generated with the EcoEx module are based on the average annual concentrations in food items and media. Consequently, concentration spikes due to episodic events (e.g., rain storms) or elevated source releases following waste additions are not evaluated. In addition the annual average approach does not capture elevated exposures during critical life stages.

- # *Exposures are predicted only for adult animals.* Because concentrations are annualized, the module predicts exposures only for adult animals; intrayear contaminant exposures to juveniles, often with very different dietary preferences, are not predicted.

- # *Dietary preferences remain constant over the year.* The EcoEx module constructs the dietary preferences for each receptor based on dietary data covering one or more seasons. Some of the seasonal variability in the diet is captured indirectly by the hierarchical algorithm used to determine the dietary preferences. However, the algorithm is implemented on data across multiple seasons and, therefore, does not necessarily reflect seasonal differences.

- # *Exposure estimates reflect a single home range setting.* The EcoEx module calculates the applied doses to receptors for a single random placement of four home range sizes.[1] As a result, the four home ranges in the site layout may not reflect the spatial variability in exposure patterns, particularly for large habitats (i.e., habitats that cover substantially greater areas than most of the home ranges).

[1] As described in Section 13 of the data collection documentation (Ecological Receptors and Habitats), each receptor is assigned to one of four discrete home range sizes, depending on the receptor-specific home range. The four home ranges are spatially linked in that the ranges overlap in a manner that reflects the dietary preferences of the predator species. Examples of this scheme are provided in Section 13.

# 3.0 Methodology

The methodology and Equations used in the Ecological Exposure module are consistent with the principles and guidelines described in the *Guidelines for Ecological Risk Assessment* (U.S. EPA, 1998). The basic Equations are commonly used in ecological risk assessments performed by the Office of Solid Waste (OSW) and other EPA program offices. In addition, similar exposure equations are in use by other non-EPA risk assessors, such as in the *Methods and Tools for Estimation of the Exposure of Terrestrial Wildlife to Contaminants* (Sample et al., 1997). The framework within which these Equations are implemented, namely a habitat-based approach to a site-based, national assessment, was developed specifically to support the ecological risk assessment for the Hazardous Waste Identification Rule. In addition, the probabilistic algorithm used to construct the habitat-specific diet for each animal at each site was created for this assessment.

The EcoEx module performs calculations for animals on the basis of the habitat and home range to which they are assigned. In essence, the calculations are implemented in three steps. First, the EcoEx module calls input data from the SW module, the TerFW module, and the AqFW module and calculates exposure concentrations that are spatially averaged over the home range or habitat, as appropriate. For example, the surface water concentration to which a receptor is exposed is the average concentration for all reaches that are included in that receptor's home range. Second, the module constructs the dietary composition for each receptor species in each habitat using an algorithm that randomly selects the dietary fraction based on: (1) the hierarchy of dietary preferences as defined by the maximum preference (e.g., 0.98 fish), and (2) the minimum and maximum preference value for each food item. The dietary composition is habitat-specific because the same species (e.g., raccoon) may be assigned to aquatic and terrestrial habitats, resulting in different dietary preferences. Lastly, the EcoEx module combines the exposure concentrations and dietary composition to estimate the total applied dose to the receptor from all contaminated food items and media.

The equations used to derive exposures from contaminant concentrations in plants, prey items, and media are presented below. It should be understood that exposures are calculated as a time series, with one value for each year in the time period under consideration. Although the Ecological Risk module calculates risks for the maximum year, it is necessary to derive the applied doses for the entire time period since the risks to different receptors will change over time. The equations below are used for each year of the time series.

## 3.1 Exposure Calculations for Terrestrial Habitats

As described in the data collection section on Ecological Habitats and Receptors, the representative terrestrial habitats include grasslands, shrub/scrub, forests, crop fields, and residential areas. Receptor doses in terrestrial habitats are a function of contaminant concentration in ingested water, soil, and prey items. The following discussion presents the methods and equations for estimating receptor dose in terrestrial habitats. A forest habitat and a forest receptor, the Eastern box turtle, are used for illustrative purposes.

### 3.1.1 Ingestion of Surface Water

The EcoEx module estimates exposure for surface water ingestion by calculating the total average concentration (dissolved plus particle-bound) found within the home range.[2] This average includes any reach and/or surface impoundment that intersects the home range. Thus, the surface water concentration is the average across waterbodies to which a receptor has access; it is assumed that the receptor does not prefer one waterbody over another. The total average concentration in surface water for each home range is calculated as shown in Equation 3-1.

*Total average concentration in surface water for a home range in a terrestrial habitat*

$$C^{i}_{sw_{ave}} = \frac{\sum Csw^{j}_{reach} + \sum Csimp^{k}_{HomeRange}}{Num_{reach_{HomeRange}} + Num_{simp_{HomeRange}}} \quad (3\text{-}1)$$

where

| | | |
|---|---|---|
| $C^{j}_{sw\_ave}$ | = | total average concentration in water to which receptor j is exposed (mg/L) |
| $Csw^{j}_{reach}$ | = | total concentration in water in the $j^{th}$ reach (mg/L) |
| $Csimp^{k}_{HomeRange}$ | = | total concentration in a surface impoundment water (mg/L) |
| $Num_{reach\_HomeRange}$ | = | number of reaches found within home range |
| $Num_{simp\_HomeRange}$ | = | number of surface impoundments that intersect home range. |

Using the forest habitat and the Eastern box turtle example, assume that several order 2 stream reaches[3] and a surface impoundment are located within the home range for the box turtle.

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[2] The EcoEx module also includes the functionality to calculate the average dissolved concentration in the waterbodies for each home range. However, the dissolved water concentration is currently not used in the exposure calculations.

[3] For this assessment, lakes, ponds, certain types of wetlands, and order 3 stream reaches and above were assumed to sustain fish and other aquatic life. These "fishable reaches" were used to define representative aquatic habitats such as stream corridors, pond margins, and forested wetlands. Order 2 streams were not assumed to be sufficient to sustain a multi-compartment, year-round, aquatic food web; therefore, only ingestion of surface water was considered for order 2 streams in terrestrial habitats.

The EcoEx module selects the stream reaches and surface impoundment that intersect the box turtle's home range (as defined in the site layout) and then calls their respective constituent concentrations from the output files from the surface water module and the surface impoundment source module. These concentrations are then averaged as shown in Equation 3-1 and used in the exposure calculation for the box turtle.

### 3.1.2 Ingestion of Plants and Prey

Static point estimates of the dietary preference fractions are frequently used in ecological risk assessments although, in fact, the dietary fraction is not known with certainty. This practice is appropriate for screening-level assessments; however, it does not address the wide variability in dietary habits across seasons and regions of the country. Therefore, the EcoEx module uses the minimum and maximum values for dietary preferences to determine the habitat-specific dietary composition (what does it eat) and to estimate the dietary fractions (how much of each item does it eat) for each receptor. The range of dietary fractions reported in the literature was evaluated to create a preference range (min/max) for categories of plants and prey considered in this exposure assessment (e.g., forage, earthworms, small birds). Studies on feeding generally suggest that behavior is best characterized as opportunistic within the context of "typical" food items. Thus, the EcoEx module ranks food items from most preferred to least preferred (defined by the maximum). A constrained, random dietary preference fraction sampling algorithm was developed to select dietary fractions at random between the minimum and maximum assuming a uniform distribution. The algorithm maintains overall dietary preferences and allows for the dietary composition to reflect the full range of variability inherent in many wildlife diets. The subroutine that performs this task is described in Text Box 3-1.

In the Eastern box turtle example, the module uses the values from the dietary preference database to identify potential food items and the range of dietary percentages associated with each item shown in Table 3-1:

**Table 3-1. Example of Dietary Preferences for Eastern Box Turtle**

| Food Item | Minimum Preference Value (%) | Maximum Preference Value (%) |
|---|---|---|
| Earthworms | 3 | 60 |
| Forage | 13 | 39 |
| Fruits | 5 | 33 |
| Soil invertebrates | 8 | 22 |
| Small herpetofauna | 0 | 10 |
| Small mammals | 0 | 10 |

**Text Box 3-1. Sampling Algorithm Used to Construct Dietary Composition of Food Items**

The issue for the HWIR analysis is to select dietary preference fractions for each food item for a given receptor in such a way that the observed bounds are honored, yet the allowable variability within the bounds is exercised in a Monte Carlo sense and the diet is complete. Expressed mathematically, the problem is:

$$Select \quad P_{ij} \quad i = 1,...,N \quad j = 1,...,M \quad Such\ that$$
$$Min_{ij} \le P_{ij} \le Max_{ij} \quad i = 1,...,N \quad j = 1,...,M$$
$$\sum_{j=1}^{M} P_{ij} = 1.0 \quad i = 1,...,N$$

where

| | | |
|---|---|---|
| N | = | number of receptors |
| M | = | number of food items (plants and prey) |
| $P_{ij}$ | = | dietary fraction of the food item for receptor i for food item j |
| $Min_{ij}$ | = | minimum observed dietary fraction of receptor i for food item j |
| $Max_{ij}$ | = | maximum observed dietary fraction of receptor i for food item j. |

The algorithm that was developed to solve this problem treats $P_{ij}$ as a "resource" to be allocated among the M food items for a given receptor. Before any dietary fractions are assigned for a given receptor i, the value of the resource remaining to be allocated is 1.0 (i.e., complete diet). After all dietary fractions have been assigned (zero fractions are allowed), the value of the resource remaining to be allocated is 0. For a given receptor i and food item j, the assignment ($P_{ij}$) must consider both the $Min_{ij}$ and the $Max_{ij}$, as well as the amount of resource remaining (dietary fraction yet

$$P_{ij} = LB_{ij} + RND(UB_{ij} - LB_{ij})$$

to be assigned).

$$LB_{ij} = Maximum[Min_{ij},\ RP_{ij} - \sum_{k=j+1}^{N} Max_{ik}]$$
$$RP_{ij} = 1.0 - \sum_{k=1}^{j-1} P_{ik}$$
$$UB_{ij} = Minimum[Max_{ij},\ RP_{ij} - \sum_{k=j+1}^{N} Min_{ik}]$$

The assignment equation for receptor i, assuming a uniform distribution for $P_{ij}$, is with the variables defined as follows:

where

LB is the lower bound of the range

As shown, the prey preference algorithm ranks the items by maximum potential dietary fraction, and then constructs the diet from these ranges, starting with the most preferred food item (largest maximum) and randomly selecting dietary fractions from within the given ranges. Following this iteration, the dietary composition might consist of 40 percent earthworms, 20 percent forage, 15 percent fruits, 15 percent other soil invertebrates, and 10 percent small mammals. The dietary preferences will be calculated for each habitat in which the Eastern box turtle appears.

Using the list of food items in our example (earthworms, forage, fruits, soil invertebrates, and small mammals), the EcoEx module then determines the contaminant concentrations in each item. The module calls for input concentrations from the Terrestrial Food Web (TerFW) module for the plant and soil community; the TerFW also provides concentrations for various prey items such as small mammals and other vertebrates. The concentrations in plants and soil fauna are defined spatially in terms of the home range area to which the receptor of interest is assigned. For example, the Eastern box turtle is assigned to the smallest home range size (<100,000 $m^2$) and, therefore, the plant and soil fauna concentrations represent the average concentration across that home range. Although the tissue concentrations in other prey species also reflect the same sort of spatial averaging, the exposure for a predatory receptor may include several species within the same prey type category even though these prey are found in different home ranges. For example, the forest habitat includes four species that fall into the prey type category of small mammal: short-tailed shrew, least weasel, deer mouse, and pine vole. If the weasel were assigned to a different home range area than the other three mammals, the tissue concentration in the weasel would reflect a different spatial average for soil concentration. In our example, the raccoon has access to all four small mammals and may consume any combination of the four. Because it is not known with certainty what the dietary preferences are for the individual species that fall into the prey type "small mammals," the EcoEx module reads the minimum and maximum values for small mammals reported by the TerFW module. The EcoEx module selects a value at random between the minimum and maximum for a prey type and uses this value as input in estimating the applied dose. This random selection is intended to reflect the large uncertainty in estimating exposure based on seasonal preferences, prey availability, and a host of other determinants. As currently implemented in HWIR99, the small mammal concentrations generated by the TerFW will be the same for all four species in the forest habitat since each species is placed in the smallest home range and is exposed to the same area-averaged soil concentration. However, for other prey types, species may be placed in more than one home range and, as a result, the tissue concentrations would be based on different spatial scales of contamination (e.g., small birds in the cropland habitat).[4] Thus, the EcoEx module randomly selects a concentration between the minimum and maximum values to address variability in the feeding preferences of a predatory receptor.[5]

[4] This functionality was built into the EcoEx module so that the spatial resolution of the exposure estimates could be refined as needed for case studies or pilot-scale evaluations of specific sites. For example, if each receptor were assigned a unique home range, the spatial differences in contaminant concentration would undoubtedly result in different estimates of tissue concentrations in species falling under a given prey type. Thus, using minima and maxima allows the EcoEx module to cover the full range of feeding possibilities in a Monte Carlo simulation.

[5] This variability refers to the site-specific feeding behavior of predators. For example, in a forest habitat, a long-tailed weasel may consume varying proportions of pine voles, deer mice, etc. depending upon the season,

In the Eastern box turtle example, the module reads the minimum and maximum concentrations for small herpetofauna and small mammals and randomly selects tissue concentration values from the category-specific ranges. For the remaining food items (earthworms, other invertebrates, forage, and fruits), the module calls for the average concentrations for the home range to which the Eastern box turtle belongs, in this case, the smallest home range (<100,000m$^2$).

Once the dietary preferences and the concentrations in various food items are established, the effective concentration in food consumed by the Eastern box turtle is calculated as shown in Equation 3-2.

*Effective concentration in food items eaten by the receptor*

$$C^i_{food} = \sum (Cplant^j_{HomeRange} \cdot Frac_{diet^k_{habitat}}) + \sum (Cprey^l_{terr} \cdot Frac_{diet^k_{habitat}}) \qquad (3\text{-}2)$$

where

| | | |
|---|---|---|
| $C^i_{food}$ | = | effective concentration in food consumed by receptor i, weighted by prey preferences (mg/kg) |
| $Cplant^j_{\_HomeRange}$ | = | concentration in j$^{th}$ plant item (i.e., fruits, grain, etc.) in the receptor's home range (mg/kg) |
| $Frac_{diet}{}^k{}_{\_habitat}$ | = | dietary fraction of the k$^{th}$ food item in the habitat to which the receptor is assigned |
| $Cprey^l_{terr}$ | = | concentration in l$^{th}$ terrestrial prey type consumed by the receptor (mg/kg). |

### 3.1.3 Ingestion of Soil

Soil ingestion through feeding and/or preening activities can constitute a significant component of wildlife exposure to contaminants, particularly for chemicals that do not accumulate appreciably in the food web. Exposure through soil ingestion is a function of soil concentration and the amount of soil ingested. As with surface water ingestion, the constituent concentration in soils is averaged over the home range. However, the EcoEx module is not required to perform any averaging to estimate the soil concentration to which a receptor is exposed. The TerFW module calculates the average soil concentrations for surficial soils and passes these outputs to the EcoEx module for each receptor in each habitat. Thus, the module

availability of prey, and a host of other site-specific characteristics relevant to the diet. It is not suggested here that the selection of a prey type concentration from the minima and maxima fully accounts for that variability. Rather, it is suggested that this approach explicitly recognizes the existence of this variability.

estimates the contribution to applied dose from ingestion of contaminated soil by multiplying the soil concentration specific to the home range by the receptor-specific food consumption rates and the percentage of soil assumed to be typical for the receptor's diet.

### 3.1.4 Calculation of Applied Dose for Receptors in Terrestrial Habitats

The applied dose of a constituent to the receptor is the summation of time-dependent concentrations in media, plants, and prey. In our example of the Eastern box turtle assigned to the forest habitat, the applied dose is a function of the ingestion of surface water, vegetative matter, earthworms, other soil invertebrates, small mammals, and soil. Equation 3.1 presents the calculations for surface water concentration and Equation 3.2 presents the calculation for the dietary component. The only other inputs required to perform this calculation are the consumption rate for food, the consumption rate for drinking water, the fraction of soil ingested as part of the diet, and fraction of the home range that "fits" within the habitat. The fraction of home range that fits within the habitat is required to avoid attributing a disproportionate amount of exposure to the study area. Although it is recognized that animals tend to use the habitats delineated for this analysis in a flexible manner, there is no reason to believe that wildlife will forage in the study area preferentially. Defining the boundaries of the ecological exposure assessment in terms of the habitat is, nevertheless, a reasonable approach for a site-based analysis to characterize spatial variability in the exposure profiles of chemical stressors.

In the Eastern box turtle example, the site layout data include a value for the home range fraction ($HomeRange_{frac}$) based on the ratio of the turtle's home range area (100,000 $m^2$) to the area delineated as forest habitat. Assume, for example, that the forest habitat is a small patch of 85,000 $m^2$ (roughly 7 percent of a 2-km area of interest). The home range fraction in this case would be 0.85 (85,000 $m^2$/100,000 $m^2$), and the applied dose to the receptor would be 0.85 of the total dose possible, based on media, plant, and prey concentrations. This adjustment reflects the fact that the box turtle is likely to obtain some of its food (15 percent in this case) from outside the study area. Equation 3-3 presents the calculation of applied dose for terrestrial receptors.

*Applied Dose to Receptor in Terrestrial Habitat*

$$Dose^{i}_{rec} = \frac{(CR^{i}_{food} \cdot C^{i}_{food}) + (C^{i}_{soil} \cdot CR^{i}_{food} \cdot Soil^{i}_{frac}) + (Csw^{i}_{ave} \cdot CR^{i}_{water})}{BodyWt^{i}_{Rec}} \cdot HomeRange_{frac} \qquad (3\text{-}3)$$

where

$Dose^{i}_{rec}$ = time-dependent applied dose of constituent to receptor i (mg/kg-d)

$CR^{i}_{food}$ = consumption rate of food for receptor i (kg/d)

$C^{i}_{food}$ = effective concentration in food consumed by receptor i, weighted by prey preferences (mg/kg)

| | | |
|---|---|---|
| $C^i_{soil}$ | = | average concentration in soil to which receptor i is exposed (mg/kg) |
| $Soil^i_{frac}$ | = | soil dietary fraction for receptor i |
| $C^i_{sw\_ave}$ | = | total average concentration in water to which receptor i is exposed (mg/L) |
| $CR^i_{water}$ | = | consumption rate of water for receptor i (L/d) |
| $BodyWt_{Rec}$ | = | body weight of receptor i (kg) |
| $HomeRange_{frac}$ | = | fraction of the receptor's home range within habitat. |

## 3.2 Exposure in Aquatic Habitats

Land-based, ecological receptors (i.e., air breathing) that live in margins of aquatic habitats (e.g., stream corridor, pond margin) are exposed through ingestion of water-based food items such as fish, benthic invertebrates, and aquatic plants, as well as through the incidental ingestion of sediment. As mentioned above, reach order 3 streams, lakes, ponds, and selected wetlands are presumed to be of sufficient quality to sustain a multicompartment aquatic food web and, therefore, serve as habitat to wildlife that eat fish and other aquatic organisms. These representative freshwater aquatic habitats are delineated so that terrestrial areas that support water quality and provide critical nesting areas are included as part of the habitat. For example, a stream habitat comprises the riparian corridor or flood plain on either side of the stream as well as the stream channel; pond and lake habitats include a terrestrial margin as well as the pond or lake basin. The methods used to delineate these areas are discussed in detail in Section 13 of the data collection documentation, Ecological Receptors and Habitats. In the following discussion, a stream habitat and the raccoon are used to illustrate how the EcoEx module calculates the applied dose to receptors in aquatic habitats. The primary difference between the dose calculations for the terrestrial and aquatic habitats is in the dietary composition.

### 3.2.1 Ingestion of Surface Water

For aquatic habitats, water ingestion is treated as it is for terrestrial habitats, except that surface impoundments are not included in calculating the average concentrations. Because surface impoundments are not intended to support aquatic life, it is assumed that receptors feeding on aquatic prey use waterbodies other than surface impoundments for food as well as for drinking water. Furthermore, it is assumed that receptors will rely only on those fishable reaches that occur within their home range as the source of both aquatic food items and drinking water.[6] It should be noted that a receptor's access to fishable reaches is not constrained by habitat. In many instances, stream habitats were located adjacent to wetlands. Because receptors are likely

[6] Second-order streams are not included in calculating the average surface water concentration for each home range in aquatic habitats.

to use reaches in each of these habitats as a source of food, adjacent aquatic habitats were delineated so that "reach crossover" could occur freely (i.e., habitats and home ranges overlapped reaches in each habitat). The stream habitat is delineated as a single contiguous corridor within the study area and, therefore, often includes multiple stream reaches. In the example of the raccoon, the home range would be randomly placed within a habitat so that it had access to at least one fishable reach. If this home range also intersected stream reaches that were assigned to another habitat (say, a forested wetlands), the total concentration would reflect the concentrations in both "in-habitat" reaches and "out-of-habitat" reaches that were included in the raccoon's home range. The total average concentration in surface water for each home range is calculated as shown in Equation 3-4.

*Total average concentration in surface water for a home range in an aquatic habitat*

$$C^{i}_{sw_{ave}} = \frac{\sum Csw^{j}_{fishable}}{Num_{fishable_{HomeRange}}} \qquad (3\text{-}4)$$

where

| | | |
|---|---|---|
| $C^{i}_{sw\_ave}$ | = | total average concentration in water to which receptor i is exposed (mg/L) |
| $Csw^{j}_{fishable}$ | = | total concentration in water in the $j^{th}$ fishable reach (mg/L) |
| $Num_{fishable\_HomeRange}$ | = | number of fishable reaches found within home range. |

There are several points worth mentioning regarding the adjacent forested wetlands habitat in our example. Wetlands are delineated as distinct habitats regardless of their landscape position relative to streams, lakes, or ponds. Thus, the HWIR modeling system treats wetlands as distinct reaches and, in this example, a forested wetlands and a stream corridor would each have been delineated and modeled separately by the system (e.g., surface water module develops water concentrations for the wetlands and stream reaches). Because the raccoon occurs in both stream and wetlands habitats, the EcoEx module would calculate an applied dose for the raccoon assigned to the wetlands and the raccoon assigned to the stream habitat, even though this receptor is allowed to use reaches from both habitats.

### 3.2.2 Ingestion of Plants and Prey

The diet for receptors in aquatic habitats is more expansive than for terrestrial habitats and includes the items listed in Section 3.1 as well as aquatic plants, benthic organisms, and fish from trophic levels three (T3) and four (T4). The module constructs each receptor's dietary composition from the prey preference inputs using the same methodology as for the terrestrial habitats. However, in our example of the raccoon, T3 fish and benthic organisms would also be listed among the potential food items. The associated constituent concentrations in aquatic food items are generated by the aquatic food web (AqFW) module for each fishable reach. In essence, it is assumed that feeding preferences for all T3 fish species would be roughly equivalent; therefore, the concentration in fish tissue is the effective average across T3 fish.[7] Only one a T4 fish (the top predator) is assigned to each reach, and, along with the concentrations in benthic organisms and aquatic macrophytes, a single, reach-specific concentration is reported for these food items from the AqFW module. Because the receptor's home range can include multiple reaches, the EcoEx module calculates the average concentration in food items across reaches to which the receptor has access (as defined by the home range). Equations 3-5 through 3-8 show the calculation of tissue concentrations in aquatic macrophytes, benthic organisms, T3 fish, and T4 fish, respectively.

*Average concentration in aquatic plants to which receptor has access*

$$C^{i}_{aqmp_{ave}} = \frac{\sum C_{aqmp^{j}_{fishable}}}{Num_{fishable_{HomeRange}}} \qquad (3\text{-}5)$$

where

$C^{i}_{aqmp\_ave}$ = average concentration in aquatic plants to which receptor i is exposed (mg/kg)

$C_{aqmp}{}^{j}{}_{fishable}$ = concentration in aquatic plants in the $j^{th}$ fishable reach in the home range (mg/kg)

$Num_{fishable\_HomeRange}$ = number of fishable reaches found within home range.

*Average concentration in benthic organisms to which receptor has access*

$$C^{i}_{benthic_{ave}} = \frac{\sum C_{benthic^{j}_{fishable}}}{Num_{fishable_{HomeRange}}} \qquad (3\text{-}6)$$

where

$C^{i}_{benthic\_ave}$ = average concentration in benthic organisms (e.g., filter feeders) to which receptor i is exposed (mg/kg)

---

[7] It is implicitly assumed that the availability of various species of T3 fish does not influence the exposure estimates; however, it is almost certainly true that prey availability of T3 species will affect the dietary choices of piscivorous animals.

| | | |
|---|---|---|
| $C_{benthic^j\_fishable}$ | = | concentration in benthic organisms in the j[th] fishable reach in the home range (mg/kg) |
| $Num_{fishable\_HomeRange}$ | = | number of fishable reaches found within home range. |

*Average concentration in T3 fish to which receptor has access*

$$C^{i}_{T3fish_{ave}} = \frac{\sum C_{AVET3fish^{j}_{fishable}}}{Num_{fishable_{HomeRange}}} \tag{3-7}$$

where

| | | |
|---|---|---|
| $C^i_{T3fish\_ave}$ | = | average concentration in T3 fish to which receptor i is exposed (mg/kg) |
| $C_{AVET3^j\_fishable}$ | = | average concentration in T3 fish in the j[th] fishable reach in the home range (mg/kg) |
| $Num_{fishable\_HomeRange}$ | = | number of fishable reaches found within home range. |

*Average concentration in T3 fish to which receptor has access*

$$C^{i}_{T4fish_{ave}} = \frac{\sum C_{T4fish^{j}_{fishable}}}{Num_{fishable_{HomeRange}}} \tag{3-8}$$

where

| | | |
|---|---|---|
| $C^i_{T3fish\_ave}$ | = | average concentration in T4 fish to which receptor i is exposed (mg/kg) |
| $C_{AVET3^j\_fishable}$ | = | concentration in T4 fish in the j[th] fishable reach in the home range (mg/kg) |
| $Num_{fishable\_HomeRange}$ | = | number of fishable reaches found within home range. |

In the raccoon example, assume that the home range placed within the stream habitat includes two distinct fishable stream reaches. It is assumed that the raccoon derives equal amounts of food from the two reaches; therefore, contaminant concentrations in aquatic macrophytes, benthic filter feeders, and trophic level 3 and 4 fish are averaged between the two reaches. The raccoon's dietary composition is constructed based on the prey preference inputs and would include both terrestrial and aquatic food items. The dietary proportion data for the raccoon are provided in Table 3-2

Based on these values, the EcoEx module might construct a dietary composition for the raccoon like the following: 45 percent soil invertebrates, 26 percent fruits, 12 percent forage, 5 percent small mammals, 7 percent benthic organisms, and 5 percent T3 fish, which sum to 100 percent, i.e., a complete diet. As mentioned previously, the dietary preferences will be calculated for each habitat in which the raccoon appears. Once the dietary preferences are established and the concentrations in various food items are called by the module, the effective concentration in food consumed by the raccoon in the stream habitat is calculated as shown in Equation 3-9.

**Table 3-2. Example of Dietary Preferences for Raccoon**

| Food Item | Minimum Preference Value % | Maximum Preference Value % |
|---|---|---|
| Soil invertebrates | 0 | 90 |
| Fruits | 25 | 86 |
| Forage | 10 | 66 |
| Small mammals | 0 | 35 |
| Small herpetofauna | 0 | 25 |
| Benthic organisms | 0 | 25 |
| T3 fish | 0 | 23 |
| T4 fish | 0 | 23 |
| Small birds | 0 | 19 |
| Earthworms | 0 | 10 |
| Grain | 0 | 10 |
| Roots | 0 | 10 |
| Silage | 0 | 10 |

*Effective concentration in food items eaten by the receptor*

$$C^{i}_{food} = \sum (Cplant^{k}_{HomeRange} \cdot Frac_{diet^{k}_{habitat}}) + \sum (Cprey^{l}_{terr} \cdot Frac_{diet^{k}_{habitat}}) + \sum (Cprey^{m}_{aq} \cdot Frac_{diet^{k}_{habitat}}) \quad (3\text{-}9)$$

where

| | | |
|---|---|---|
| $C^{i}_{food}$ | = | effective concentration in food consumed by receptor i, weighted by prey preferences (mg/kg) |
| $Cplant^{j}_{\_HomeRange}$ | = | concentration in $j^{th}$; plant item (e.g., fruits, grain) in the receptor's home range (mg/kg) |
| $Frac_{diet}{}^{k}{}_{\_habitat}$ | = | dietary fraction of the $k^{th}$ food item in the habitat to which the receptor is assigned |
| $Cprey^{l}_{terr}$ | = | concentration in $l^{th}$ terrestrial prey type consumed by the receptor (mg/kg) |
| $Cprey^{m}_{aq}$ | = | concentration in $m^{th}$ aquatic prey type consumed by the receptor (mg/kg). |

### 3.2.3 Sediment Ingestion

In aquatic habitats, some receptors may be exposed through the incidental ingestion of contaminants in sediment during foraging activities. This exposure pathway may be significant for certain types of chemicals and receptors since the sediment often serves as a sink for environmental pollutants. Exposure through sediment ingestion is a function of sediment concentration and the amount of sediment ingested. As with the surface water ingestion, the constituent concentration in sediment is averaged across reaches to which the receptor has access. Unlike the ingestion of soil (where the averaging has already been performed), the EcoEx module includes an algorithm to calculate the average sediment concentration, as shown by Equation 3-10. Again, it is assumed that sediment is ingested only from fishable reaches; sediments from streams of order 2 or lower and from surface impoundments are excluded.

*Total average concentration in sediment for a home range in an aquatic habitat*

$$C^{i}_{sed_{ave}} = \frac{\sum Csed^{j}_{fishable}}{Num_{fishable_{HomeRange}}} \quad (3\text{-}10)$$

where

| | | |
|---|---|---|
| $C^{i}_{sed\_ave}$ | = | total average concentration in sediment to which receptor i is exposed (mg/kg) |
| $Csed^{j}_{fishable}$ | = | total concentration of sediment in the $j^{th}$ fishable reach (mg/kg) |
| $Num_{fishable\_HomeRange}$ | = | number of fishable reaches found within home range. |

The amount of sediment ingested is estimated in the same manner as the amount of soil ingested. The EcoEx module estimates the contribution to applied dose from ingestion of contaminated sediment by multiplying the sediment concentration specific to the home range by the receptor-specific food consumption rates and the percentage of sediment assumed to be typical for the receptor's diet.

### 3.2.4 Calculation of Applied Dose for Receptors in Aquatic Habitats

For receptors in aquatic habitats, the applied dose is the summation of time-dependent concentrations in media, plants, and prey from both terrestrial and aquatic origins. In our example of the raccoon assigned to a stream habitat, the applied dose is a function of the ingestion of surface water, soil invertebrates, terrestrial vegetative matter, small mammals, benthic organisms, T3 fish, soil, and sediment. As shown in Equation 3-11, the inputs required to perform this calculation are essentially the same as those required for terrestrial receptors (e.g., consumption rates, sediment and soil fraction, body weight).

In the raccoon example, the site layout data includes a value for the home range fraction ($HomeRange_{frac}$) based on the ratio of the raccoon's home range area bin (100,000,000 $m^2$) to the area delineated as stream habitat. Given the large size of the raccoon's habitat relative to the 2-km study area size, it is not surprising that, in many cases, the fraction of the raccoon's home range may fall close to 10 percent. For a small stream corridor of approximately 500,000 $m^2$, the home range fraction would be below the minimum value of 10 percent. Therefore, the applied dose to the raccoon would be 0.1 of the total dose possible, based on media, plant, and prey concentrations to which it is exposed. As with the box turtle example in terrestrial habitats, this adjustment reflects the fact that the raccoon is highly likely to obtain a significant percentage of its food (90 percent in this case) from outside the study area. Indeed, for receptors with home range sizes in the top two size categories (e.g., apex predators, deer), it is not unusual to find that less than 25 percent of the home range is contained within the habitat. Consequently, using a minimum value of 10 percent ensures that risks are attributed to habitat usage in a reasonable manner without being overly conservative.[8] Equation 3-11 presents applied dose calculation for aquatic receptors.

[8] There is considerable uncertainty associated with prorating exposures based on area. Wildlife use a variety of foraging areas depending on season, prey availability, and numerous other factors.

*Applied Dose to Receptor in Aquatic Habitat*

$$Dose^{i}_{rec} = \frac{(CR^{i}_{food} \cdot C^{i}_{food}) + CR^{i}_{food}\,[(C^{i}_{soil} \cdot Soil^{i}_{frac}) + (C^{i}_{sed} \cdot Sed^{i}_{frac})] + (Csw^{i}_{ave} \cdot CR^{i}_{water})}{BodyWt^{i}_{Rec}} \cdot HomeRange_{frac} \quad (3\text{-}11)$$

where

| | | |
|---|---|---|
| $Dose^{i}_{rec}$ | = | time-dependent applied dose of constituent to receptor i (mg/kg-d) |
| $CR^{i}_{food}$ | = | consumption rate of food for receptor i (kg/d) |
| $C^{i}_{food}$ | = | effective concentration in food consumed by receptor i, weighted by prey preferences (mg/kg) |
| $C^{i}_{soil}$ | = | average concentration in soil to which receptor i is exposed (mg/kg) |
| $Soil^{i}_{frac}$ | = | soil dietary fraction for receptor i |
| $C^{i}_{sed}$ | = | average concentration in sediment to which receptor i is exposed (mg/kg) |
| $Sed^{i}_{frac}$ | = | sediment dietary fraction for receptor i |
| $C^{i}_{sw\_ave}$ | = | total average concentration in water to which receptor i is exposed (mg/L) |
| $CR^{i}_{water}$ | = | consumption rate of water for receptor i (L/day) |
| $BodyWt_{Rec}$ | = | body weight of receptor i (kg) |
| $HomeRange_{frac}$ | = | fraction of the receptor’s home range within habitat. |

# 4.0 Implementation

The flowchart shown in Figure 4-1 illustrates the generalized structure of the Ecological Exposure Module.

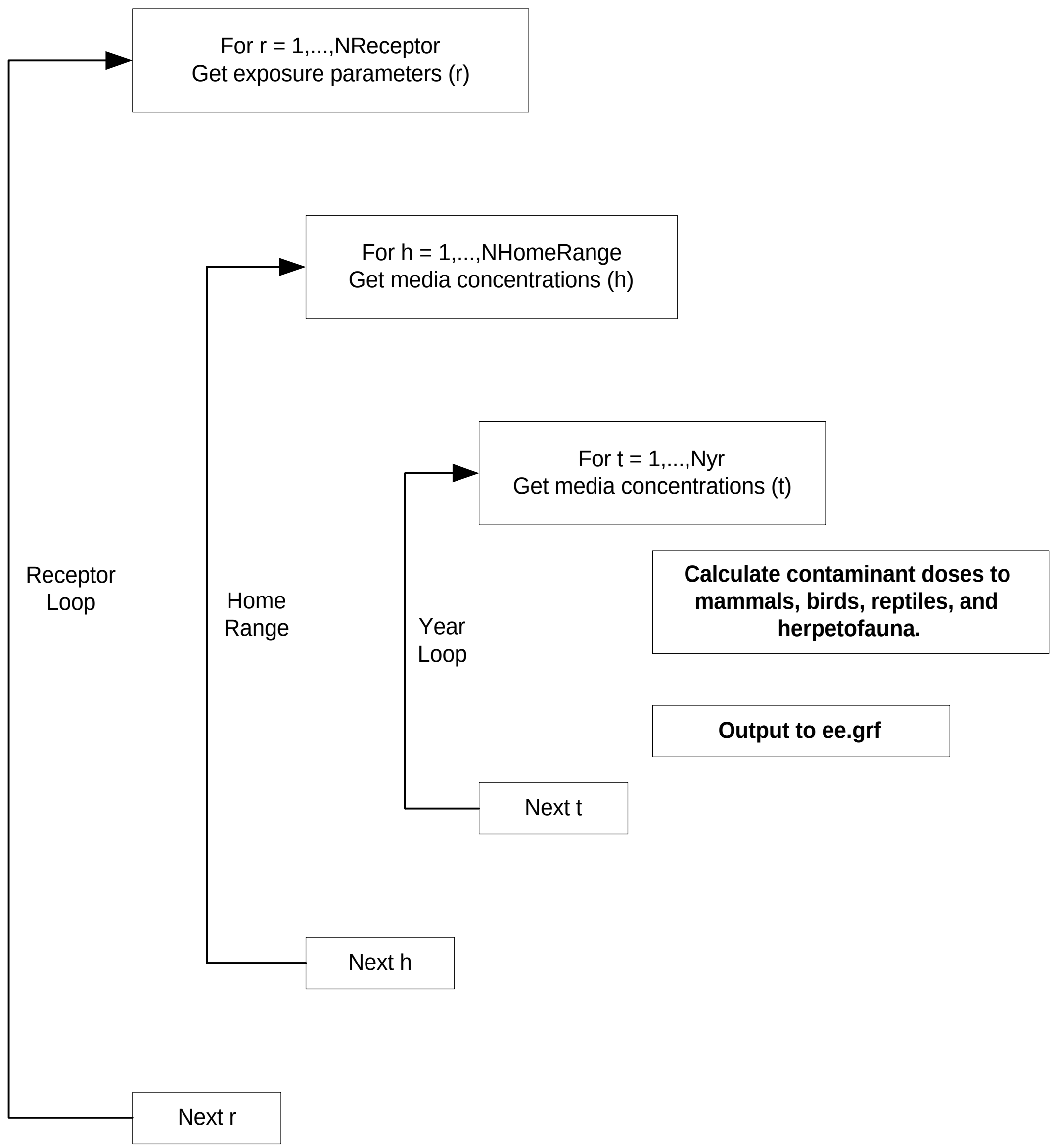


**Figure 4-1. Conceptual flow diagram of major functionality of Ecological Exposure Module.**

# 5.0 References

Sample, B.E., M.S. Alpin, R.A. Effroymson, G.W. Suter, and C.J.E.Welsh. 1997. Methods and Tools for Estimation of the Exposure of Terrestrial Wildlife to Contaminants. Environmental sciences Division Publication Number 4650. Oak Ridge National Laboratory. Oak Ridge, TN.

U.S. EPA (Environmental Protection Agency). 1998. *Guidelines for Ecological Risk Assessment.* EPA/630/R-95/002F. Risk Assessment Forum. Washington, DC. April.

# Appendix A

# Inputs and Outputs

# Appendix A

# Inputs and Outputs

The Ecological Exposure Module receives inputs from its module-specific input file, ee.ssf, the generic site layout file (sl.ssf), and modeled inputs from the following other modules: Terrestrial Food Web Module (tf.grf), Aquatic Food Web module (af.grf), Surface Water module (sw.grf), and those source modules outputting (to a common grf file, sr.grf) a "true" for the surface water logical flag, *SrcH2O*. These sources are the Land Application Unit, Landfill, Wastepile, and Surface Impoundment; currently, only the surface impoundment reports true for this flag. The Ecological Exposure module outputs are written to the ee.grf file. (All exposure outputs are 3-dimensional arrays indexed on time, habitat, and receptor.)

All input and output variables are listed and described in Tables A-1 through A-7.

**Table EE-1. Ee.ssf Input Parameters (Module-Specific Inputs)**

| Input Parameters | Units | Description |
|---|---|---|
| *BodyWt_rec* | kg | Body weight of each receptor. |
| *CR_food* | kg/d | Consumption rate of food items for each receptor. |
| *CR_water* | L/d | Consumption rate of water for each receptor. |
| *CRfrac_sed* | mass fraction | Consumption rate of sediment for each receptor. |
| *CRfrac_soil* | mass fraction | Consumption rate of surficial soil for each receptor. |
| *HabitatIndex* | unitless | Index of habitat types. |
| *HabitatType* | NA | Description of habitat types. |
| *MaxPreyPref_HabRange* | unitless | Maximum dietary preference for items found in a habitat range. |
| *MinPreyPref_HabRange* | unitless | Minimum dietary preference for items found in a habitat range. |
| *NumHabitat* | unitless | Number of habitat types represented. |
| *NumPrey* | unitless | Number of potential prey items. |
| *PreyIndex* | unitless | Numerical index of potential prey items. |
| *PreyType* | NA | Description of each prey item. |

**Table EE-2. Sl.ssf Input Parameters (Module-Specific Site Layout Inputs)**

| Input Parameters | Units | Description |
|---|---|---|
| *HabArea* | $m^2$ | Area of habitat. |
| *HabIndex* | unitless | Index of habitat type. |
| *HabNumRange* | unitless | Number of home ranges per habitat. |
| *HabNumWBNRch* | unitless | Number of WBN reaches that impact each habitat range. |
| *HabRangeAreaFrac* | fraction | Fraction of total home range area that falls within each habitat. |
| *HabRangeFishWBNIndex* | unitless | Index of WBN containing fishable reaches that impact each habitat range. |
| *HabRangeNumSISrc* | unitless | Number of surface impoundments that intersect each habitat range. |
| *HabRangeNumWBNRch* | unitless | Number of WBN reaches found within each habitat range. |
| *HabRangeNumWSSub* | unitless | Number of watersheds that impact each habitat range. |
| *HabRangeRecIndex* | unitless | Receptor index associated with each habitat range. |
| *HabRangeWBNIndex* | unitless | Index of WBN that impacts each habitat range. |
| *HabRangeWBNRchIndex* | unitless | Index of WBN reaches that impact each habitat range. |
| *HabRangeWSSubIndex* | unitless | Index of watershed that impacts each habitat range. |
| *HabType* | NA | Type of representative habitat. |
| *HabWBNIndex* | unitless | Index of WBN that impacts each habitat. |
| *HabWBNRchFrac* | unitless | Fraction of habitat range impacted by each reach. |
| *HabWBNRchIndex* | unitless | Index of WBN reaches that impact each habitat. |
| *HRangeFishWBNRchIndex* | unitless | Index of fishable reaches that impact each habitat range. |
| *HRangeNumFishWBNRch* | unitless | Number of fishable reaches that cross each habitat range. |
| *NumHab* | unitless | Number of habitats selected for site simulation. |
| *NumReceptor* | unitless | Complete receptor list across all habitat types. |

*(continued)*

**Table EE-2. (continued)**

| Input Parameters | Units | Description |
|---|---|---|
| *NumWBN* | unitless | Number of waterbody networks. |
| *NumWSSub* | unitless | Number of watershed sub basins. |
| *ReceptorIndex* | unitless | Indices assigned to each receptor. |
| *ReceptorName* | NA | Name of receptor. |
| *ReceptorType* | NA | Description of receptor. |
| *WBNFishableRchIndex* | unitless | Index of reaches that are fishable. |
| *WBNNumFishableRch* | unitless | Number of fishable reaches. |
| *WBNNumRch* | unitless | Number of reaches for each waterbody network. |

**Table EE-3. Af.grf Input Parameters (Aquatic Food Web Module Inputs)**

| Input Parameters | Units | Description |
|---|---|---|
| *Caqmp* | mg/kg | Concentration of contaminant in aquatic plants. |
| *CaqmpNY* | unitless | Number of years in the time series corresponding to this variable. |
| *CaqmpYR* | year | Time series of years corresponding to this variable. |
| *Cbenthff* | mg/kg | Concentration of contaminant in benthic organisms. |
| *CbenthffNY* | unitless | Number of years in the time series corresponding to this variable. |
| *CbenthffYR* | year | Time series of years corresponding to this variable. |
| *CT3Fish* | mg/kg | Concentration of contaminants in trophic level 3 fish. |
| *CT3FishNY* | unitless | Number of years in the time series corresponding to this variable. |
| *CT3FishYR* | year | Time series of years corresponding to this variable. |
| *CT4Fish* | mg/kg | Concentration of contaminants in trophic level 4 fish. |
| *CT4FishNY* | unitless | Number of years in the time series corresponding to this variable. |
| *CT4FishYR* | year | Time series of years corresponding to this variable. |

**Table EE-4. Sr.grf Input Parameters (Source Module Inputs)**

| Input Parameters | Units | Description |
|---|---|---|
| *SrcH2O* | NA | Flag for surface water presence. |
| *SWConcTot* | mg/L | Contaminant concentration in surface water. |
| *SWConcTotNY* | unitless | Number of years in the time series corresponding to this variable. |
| *SWConcTotYR* | year | Time series of years corresponding to this variable. |

**Table EE-5. Sw.grf Input Parameters (Surface Water Module Inputs)**

| Input Parameters | Units | Description |
|---|---|---|
| *WBNConcWaterTot* | mg/L | Dissolved concentration in surface water used as drinking water source by cattle. |
| *WBNConcWaterTotNY* | unitless | Number of years in the times series corresponding to this variable. |
| *WBNConcWaterTotYR* | year | Time series of years corresponding to this variable. |

**Table EE-6. Tf.grf Input Parameters (Terrestrial Food Web Module Inputs)**

| Input Parameters | Units | Description |
|---|---|---|
| *C<animals>_<max or min>NY* | unitless | Number of years in the time series corresponding to this variable. |
| *C<animals>_<max or min>* | mg/kg | Concentration of contaminant found in herbiverts and omniverts. |
| *C<animals>_<max or min>YR* | year | Time series of years corresponding to this variable. |
| *C<animals>_HabRange* | mg/kg | Concentration of contaminant found in invertebrates and worms. |
| *C<animals>_HabRangeNY* | unitless | Number of years in the time series corresponding to this variable. |
| *C<animals>_HabRangeYR* | year | Time series of years corresponding to this variable. |
| *C<animals>_sm_<max or min>* | mg/kg | Concentration of contaminant found in small birds, herpetofauna, and mammals. |
| *C<animals>_sm_<max or min>YR* | year | Time series of years corresponding to this variable. |
| *C<animals>_sm_<max or min>NY* | unitless | Number of years in the time series corresponding to this variable. |
| *CTdaAveHabRange* | μg/g | Average depth average soil concentration in each habitat range. |
| *CTdaAveHabRangeNY* | unitless | Number of years in the time series corresponding to this variable. |
| *CTdaAveHabRangeYR* | year | Time series of years corresponding to this variable. |
| *CTssAveHabRange* | μg/g | Average depth average soil concentration in each habitat range. |
| *CTssAveHabRangeNY* | unitless | Number of years in the time series corresponding to this variable. |
| *CTssAveHabRangeYR* | year | Time series of years corresponding to this variable. |
| *P<plant type>_HabRangeNY* | unitless | Number of years in the time series corresponding to this variable. |
| *P<plant type>_HabRangeYR* | year | Time series of years corresponding to this variable. |
| *P<plant type>_HabRange* | mg/kg | Concentration of contaminant found in exfruit, exveg, forage, grain, root, and silage. |

**Table EE-7. Ee.grf Output Parameters (Eco Exposure Module Outputs)**

| Output Parameters | Units | Description |
|---|---|---|
| *Dose_rec* | mg/kg-d | Dose of contaminant to receptor. |
| *Dose_recNY* | unitless | Number of years in the time series corresponding to this variable. |
| *Dose_recYR* | year | Time series of years corresponding to this variable. |