Terrestrial Wildlife Exposure Model (TWEM) and the Spatially Explicit Exposure Model (SEEM): Two Methods to Integrate Exposure and Effects in a Heterogeneous Environment

U.S. Army Center for Health Promotion and Prev. Medicine
Health Effects Research Program

Problem:

- Assumptions used in Ecological Risk Assessments are conservative and unrealistic

  - Exposures are patchy
  - Habitat not usually considered

- ERAs are expensive
- Delays in the risk assessment process
- Can affect readiness

Problem: continued

- Lack of consistency for risk estimation
  - Human health standardized (CERCLA), but not necessarily for RCRA.
  - Significant variation in Ecological Risk Assessment methods:
    - Regional variation
      - EPA, State
      - Different species, communities
- Lack of refined data
  - Toxicological / refined benchmarks
  - Exposure criteria, methods, models
- Costly in time and money

Technical Objectives -

- Integrate toxicology into risk assessment
  - Understand class-specific targets
- Exposure:
  - Life history information (species specific).
  - Bioaccumulation information (chemical specific).
  - Ecological information (spatial heterogeneity).
- Toxicity:
  - Refined benchmarks (mg/kg-d)
- Probabilistic output
- Consistent with current guidance
- Referenced

- **Risk Assessment Process**
  - Terrestrial Wildlife Exposure Model (TWEM)
    - Models oral exposures
    - Food web modeling
    - Screening and modified (Tier II and Tier III) ERAs
    - Contains databases
      - Life History Database
      - Bioaccumulation Database
  - Spatially Explicit Exposure Model (SEEM)
    - Use for Tier II or III
    - Chemical specific
    - Requires adequate site characterization data

Terrestrial Wildlife Exposure Model (TWEM)

- Uses conventional approach
  - Output – oral exposure mg/kg-d
- Integrates useful databases
  - Life History Database
    - Contains species-specific profiles – 57 species
    - Exposure information
      - Regional bw values, food intake, home range
      - Population information
  - Bioaccumulation Database
    - Has literature derived regression values
    - BaFs
    - Log Kow-based values

Generalized Oral Exposure Model

$$E_o = \sum_{i=1}^{m} (I_i * C_i)$$

Where:

E_o = oral exposure (mg/kg/d)

m = number of ingested media (e.g., food, water or soil)

I_i = ingestion rate for medium(i) (kg/kg/d or L/kg/d)

C_i = contaminant concentration in medium (i) (mg/kg or mg/L)

Bioaccumulation Database

Microsoft Access

File Edit View Insert Format Records Tools Window Help

Type a question for help

TWM1BAF : Database (Access 2000 file format)

Open Design New

TWEM BAF Database

Model Parameters

CASID	Chemical	Synonyms
7439921	Col. Pigment metal 4	Lead

Regression Model Parameters | Bioaccumulation Factors | LogKow Model Parameters

Food	Medium	Slope	Intercept	N	RMSE	R2	P	Reference	Comments
Benthic Invertebrates	Sediment	0.801	-0.776	114	0.568	0.35	0.001	Bectel-Jacobs 1998b (all depu	
Birds	Soil								
Earthworms	Soil	0.807	-0.218	245	1.66271	0.58	0.0001	Sample et al. 1999	
Fish	Surface Water								
Fruits	Soil								
Other/Unknown	Not Applicable								
Plants	Soil	0.561	-1.328	189	1.89162	0.24	0.0001	Bechtel-Jacobs 1998a	
Reptiles	Soil								
Seeds	Soil								
Small Mammals	Soil	0.4422	0.0761	138	0.97193	0.37	0.0001	Sample et al. 1998b (general)	
Terrestrial Invertebrates	Soil								

Note: Add/edit/delete food and/or chemicals in the TWEM System Database.

Exit

tblSysMods

food group or item

NUM

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Life History Database

TWEM Life History Database

Select a Receptor Type: Red Fox

Active Receptor Types Only

General | Food Ingestion Rate | Proportion of Soil in Diet | Water Ingestion Rate | Body Weight | Home Range | Diet

Location: Not Reported

Season: Not Reported

Habitat: Not Reported

Sex: Not Reported

Age: Not Reported

Elevation: Not Reported

Food	Weight	Volume	Occur
Plants	0.311		
Other/Unknown	0.028		
Small Mammals	0.617		
Birds	0.002		

proportion of food in diet by occurrence (unitle

Add Food | Delete Food

Reference: Knable, 1974

Comments: Percent wet weight / stomach contents
Percent wet weight / stomach contents

Set This Record as the Default Values

Record: 1 of 1

Add Diet

Add New Receptor Type

Exit

Objects: Tables, Queries, Forms, Reports, Pages, Macros, Modules

Groups: Favorites

ion description of study

NUM

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Tier 1 Terrestrial Wildlife Exposure Model

File Tools Reports... Help

Habitats
Forest Deciduous
Receptors
AOC #2

System Libraries

Name
Plants
Seeds
Terrestrial Inverteb

Red-Winged Blackbird

General | Diet | Taxonomy

General

Name: Red-Winged Blackbird

Type: Agelaius phoeniceus (Terrestrial Organism)

Life History Parameter:	Value	Units		Type	Reference	Comments
Food Ingestion Rate (FIR):	0.658	kg/kg/	...	Tier 1 Defaul	Nagy, 1987	
Soil Proportion of Food (Ps):	0.000		...	Tier 1 Defaul	No Value	
Water Ingestion Rate (WIR):	0.157	L/kg/d	...	Tier 1 Defaul	Calder and Braun, 1983	
Body Weight (BW):	0.057	kg	...	Tier 1 Defaul	none	
Home Range (HR):	11.000	acre	...	Tier 1 Defaul	same as AOC size	
	AUF=1.00	Spatial				

Save Undo Close

2/24/2004

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Tier 1 Terrestrial Wildlife Exposure Model

File Tools Reports... Help

- Habitats
  - Forest Deciduous
- Receptors
- AOC #2
  - Habitats
    - Slow Moving Shallow Water (Per

System Libraries

Name
Plants
Other/Unknown
Terrestrial Invertebrate

Meadow Vole

General | Diet | Taxonomy

Diet

Reference: Lindroth and Batzli, 1984

Comments: Percent volume / stomach conten

Select Diet | Customize Diet | Set Food Concentrations

Food	Pi
Plants	0.87
Other/Unknown	0.12
Terrestrial Invertebrates	0.01

Food	Chemical	Calculation Type	Food Conc.	Pathway
Plants	3-Chloropropene	Rule-based	110	SOIL
Plants	Acrylonitrile	Rule-based	40	SOIL
Other/Unknown	3-Chloropropene	Rule-based	0	NA
Other/Unknown	Acrylonitrile	Rule-based	0	NA
Terrestrial Invertebrates	3-Chloropropene	Rule-based	110	SOIL
Terrestrial Invertebrates	Acrylonitrile	Rule-based	40	SOIL

Save | Undo | Close

2/24/2004 10:43 AM

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Tier 1 Terrestrial Wildlife Exposure Model

File Tools Reports... Help

Set Food Concentrations for American Robin

American Robin

	Food	Chemical	Calculation
	Plants	Aroclor 1260	Regression model
	Plants	2,4,6-trinitrotoluene	Rule-based (LogKo
	Plants	Lead	Rule-based (Regres
	Other/Unknown	Aroclor 1260	Rule-based (BAF m
	Other/Unknown	2,4,6-trinitrotoluene	Rule-based (BAF m
	Other/Unknown	Lead	Rule-based (BAF m
	Earthworms	Aroclor 1260	Rule-based (BAF m
	Earthworms	2,4,6-trinitrotoluene	Rule-based (BAF m
▶	Earthworms	Lead	Rule-based
	Terrestrial Invertebr.	Aroclor 1260	Rule-based (BAF m
	Terrestrial Invertebr.	2,4,6-trinitrotoluene	Rule-based (BAF m
	Terrestrial Invertebr.	Lead	Rule-based (BAF m

Calculation Type

- Measured
- Rule-based (Regression, BAF, LogKow)
- Regression Model
- BAF Model
- LogKow Model

Food Parameters

Medium/Pathway: Soil

Moisture Content: 0.000

Lipid Content: 0.000

Assimilation Efficiency: 1.000

Rule-based: no model inputs

Food Concentration: 0.000 mg/kg Estimate

Regression Model - Slope: 0.807 Intercept: -0.218

Bioaccumulation Factor: 0.000 (mg/kg)/(mg/kg

Not Applicable

LogKow Model - Slope: 0.807 Intercept: -0.218

Reference & Comments

Reference: Sample et al. 1999

Comments:

Ok Cancel

1/5/2006 10:22 AM

Estimated Exposure Levels (Data Dump with Food Breakdown)

1 of 2 73% Total:16 100% 16 of 16

Preview

Estimated Exposure Levels (Data Dump with Food Breakdown

February 24, 2004

Area of Concern:	Receptor Name	Receptor Type	Chemical Name	Chemical Synonyms	Exposure (mg/kg/d) Soil	Sed	Water		Food	Total
AOC #2	Canada Geese	Canada Geese	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.00	0.00	0.00	Plants	0.00	0.00
AOC #2	Canada Geese	Canada Geese	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.00	0.00	0.00	Seeds	0.00	0.00
AOC #2	Canada Geese	Canada Geese	Chloroallylene	3-Chloropropene	0.00	0.00	0.00	Plants	0.00	0.00
AOC #2	Canada Geese	Canada Geese	Chloroallylene	3-Chloropropene	0.00	0.00	0.00	Seeds	0.00	0.00
AOC #2	Meadow Vole	Meadow Vole	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.06	0.00	0.00	Plants	2.01	2.07
AOC #2	Meadow Vole	Meadow Vole	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.06	0.00	0.00	Other/Unknown	0.00	2.07
AOC #2	Meadow Vole	Meadow Vole	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.06	0.00	0.00	Terrestrial Invertebrates	0.02	2.07
AOC #2	Meadow Vole	Meadow Vole	Chloroallylene	3-Chloropropene	0.15	0.00	0.00	Plants	5.53	7.69
AOC #2	Meadow Vole	Meadow Vole	Chloroallylene	3-Chloropropene	0.15	0.00	0.00	Other/Unknown	0.00	7.69
AOC #2	Meadow Vole	Meadow Vole	Chloroallylene	3-Chloropropene	0.15	0.00	0.00	Terrestrial Invertebrates	0.06	7.69
AOC #2	Red-Winged Blackbird	Red-Winged Blackbird	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.00	0.00	0.00	Plants	0.00	0.00
AOC #2	Red-Winged Blackbird	Red-Winged Blackbird	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.00	0.00	0.00	Seeds	0.00	0.00
AOC #2	Red-Winged Blackbird	Red-Winged Blackbird	Acrylonitrile	Propenonitrile; Vinyl cyanide	0.00	0.00	0.00	Terrestrial Invertebrates	0.00	0.00
AOC #2	Red-Winged Blackbird	Red-Winged Blackbird	Chloroallylene	3-Chloropropene	0.00	0.00	0.00	Plants	0.00	0.00
AOC #2	Red-Winged Blackbird	Red-Winged Blackbird	Chloroallylene	3-Chloropropene	0.00	0.00	0.00	Seeds	0.00	0.00
AOC #2	Red-Winged Blackbird	Red-Winged Blackbird	Chloroallylene	3-Chloropropene	0.00	0.00	0.00	Terrestrial Invertebrates	0.00	0.00

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TWEM - summary

- Calculates exposure (mg/kg-d) for many wildlife species
- User guided interface
- Has internal seamless databases
  - Can access externally
- Allows for use of site-specific data
- Provides for consistent use
  - Comparison of sites
  - Remediation alternatives
  - Regulatory review
  - Assumptions referenced

SEEM within the ERA Framework

EXAMPLE APPLICATIONS

Exposure Assessment: visualize exposure pathways – identify where chemicals and habitats intersect; assess impact of receptor habits on exposure; increase realism – species only where habitat available

Effects Assessment: visualize intersection of potential effects for different receptors

Iteration and Sensitivity: run multiple times with variable inputs to evaluate risk driving assumptions

SEEM within the ERA Framework

EXAMPLE APPLICATIONS

Risk Characterization: identify areas of concern; identify local populations and associated habitat types that are susceptible

Risk Communication/Feasibility: illustrate problematic portions of the site; evaluate remedial alternatives

Risk Management: increase realism – attention to areas where habitat and chemicals intersect – avoid concluding risk in an area in which a local population would not be present

Programming Design

- Setup as a module within Army Risk Assessment Modeling System (ARAMS) and may also be run as a standalone exposure model
- SEEM is designed with C++ code constructed using *Borland C++ Builder Professional ver 6.0*
- SEEM uses *Microsoft Excel* for report viewing

Conceptual Description – Foraging Submodel

Static (Nesting) Submodel

- Each animal is placed randomly (guided by habitat suitability) at a nesting position on the landscape
- The nest location for each individual remains fixed for remainder of analysis
- The animal ‘leaves the nest’ to forage a specified number of times per day within the foraging radius

- Free-Ranging Foraging Submodel
  - Various foraging events based on home range, but changes daily, weighted on HS.
  - Probability of locating a starting point in any polygon is proportional to habitat suitability

SEEM – inputs

In ARAMS, SEEM will collect input data from:

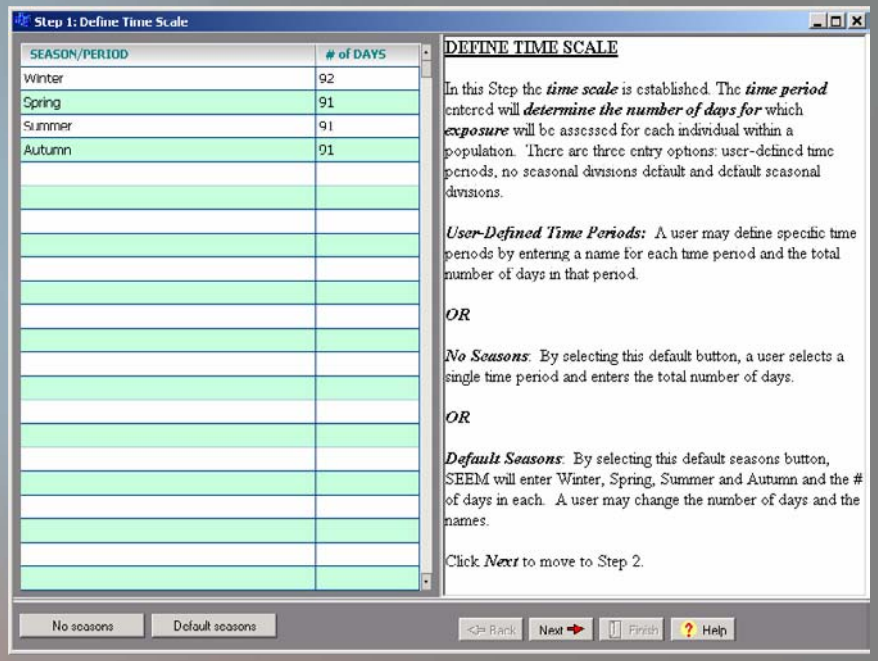
- **Chemical Database**
- **Bioaccumulation Factor Database**
- **Life History Database**
- **Terrestrial Toxicity Database**
- **Habitat Suitability Index Database**

From: USFWS – D. Menke

Model Operation

Guided Input Step 1: Define the time period/scale

- Specify the number of days in the modeling period
- Exposure will be estimated for each individual for each specified day
- Users may specify time period by season (if season-specific inputs are available) or as one fixed time period



Model Operation

Guided Input Step 2: List Chemicals

- List of chemicals to be analyzed
- Provide CASRN and chemical name
- SEEM runs on a single chemical at a time, however inputs for all chemicals of interest may be entered together

Model Operation

Guided Input Step 3: Define Food Items and Bioaccumulation Factors

- Enter food item name and exposure medium
- Select chemical
- Bioaccumulation factors are used to estimate the body burden for each chemical and therefore the dose of chemicals in food/diet items
- Enter a chemical-specific BAF value OR choose to enter a measured body burden concentration with co-located medium concentration (from which a BAF will be calculated)

Model Operation

Guided Input Step 3: Define Food Items and Bioaccumulation Factors

- The BAF is applied to each exposure concentration
- References for each input may be entered in each step and will be tracked by SEEM

Model Operation

Guided Input Step 3: Define Bioaccumulation Factors

Step 3: Define Food Items and Bioaccumulation Factors

FOOD ITEM	MEDIUM
Small Mammal	soil

CHEMICAL	CASRN
Lead	

TISSUE CONCENTRATION mg/kg-body	MEDIUM CONCENTRATION mg/kg-soil dw	BAF
		0.0061

REFERENCE

DEFINE FOOD ITEMS AND BIOACCUMULATION FACTORS

A subset of species are considered food items. As such they are not evaluated directly in SEEM, however they are consumed by higher order species. Body burden concentrations are required in order to include these species in SEEM. Two options are provided for use of a bioaccumulation factor (BAF).

First, enter the name of each food item.

Chemical names entered in Step 2 will appear in the chemical pull-down menu.

Next, highlight a food item and a chemical.

Finally, enter the ***BAF***. Two options are available for BAF entry.

Option 1: Enter a measured tissue concentration and co-located medium concentration. Based on these values SEEM will calculate a BAF value which will appear in the BAF cell.

OR

Option 2: Enter a BAF value in the BAF cell.

Back | Next | Finish | Help

Model Operation

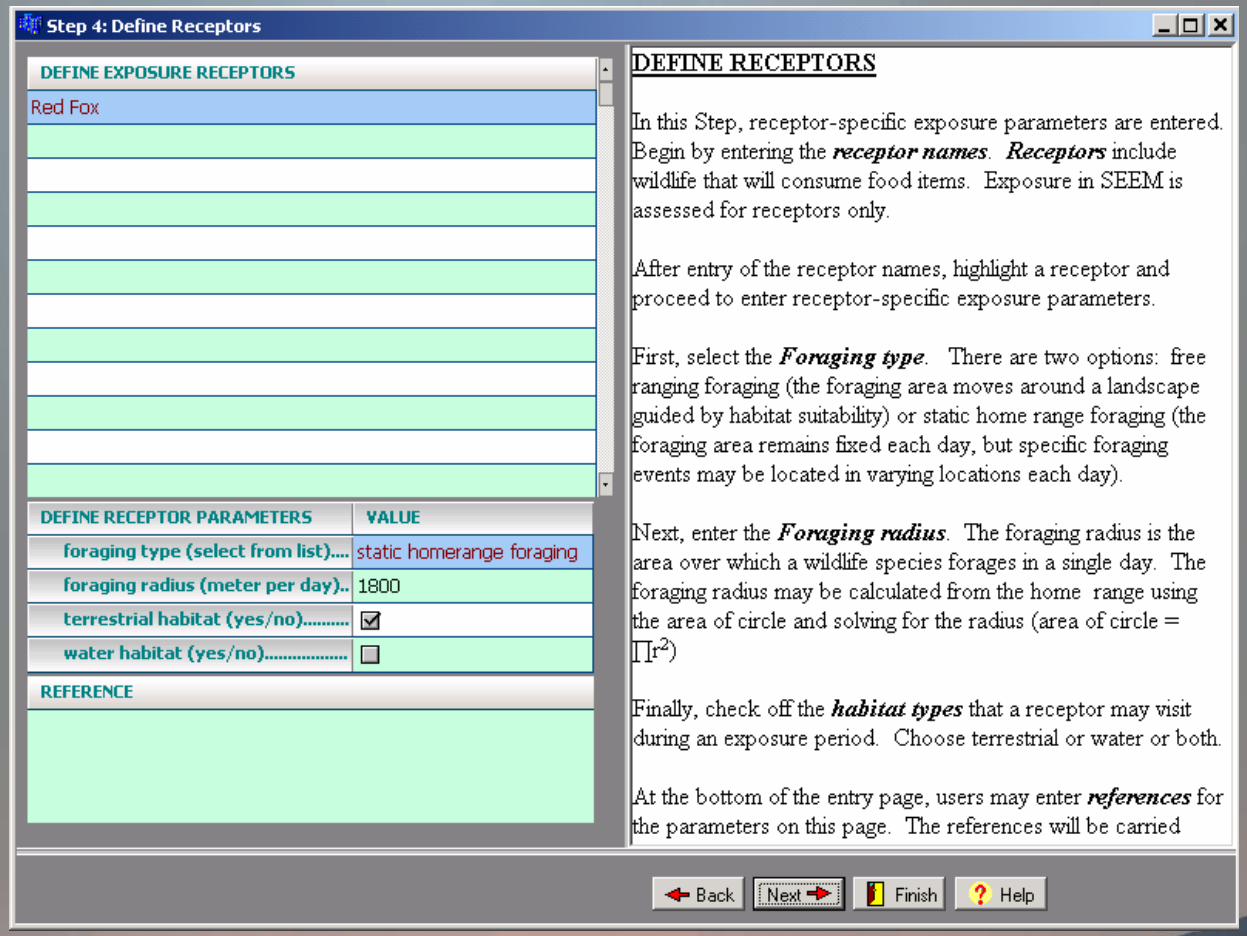
Guided Input Step 4: Define Receptors

- Enter name of wildlife receptors of interest
- Select applicable foraging type (choose one): free-ranging or static home range; food items entered in Step 3
- Enter the foraging radius (=radial distance that defines the area over which an individual forages in a day)
- Specify whether the wildlife species forages in soil, water or both

From: USFWS – D. Menke

Model Operation

Guided Input Step 4: Define Receptors



Model Operation

Guided Input Step 5: Define Diets

- Select a receptor of interest
- Enter the food, water and other applicable media ingestion rates
- For food ingestion, specify the percent in diet for each diet item – the total must add up to 100%
- Note that the adjustment of soil/sediment incidental ingestion should be completed outside of SEEM; SEEM accepts a soil ingestion rate

From: USFWS – R. West

Model Operation

Guided Input Step 5: Define Diets

Step 5: Define Diets

SELECT RECEPTOR
Red Fox

INGESTION RATES :	VALUE
Soil (kg-soil/kg-body wt per day).....	0.003
Sediment (kg-sed./kg-body wt per day).....	0
Water (L-water/kg-body wt day).....	0
Breathing Rate (m3/kg-body wt per day).....	0
Food (kg-food/kg-body wt per day).....	0.097

DIET ITEMS	% IN DIET (AVERAGE FOR ALL SEASONS)
small mammal	100

REFERENCES:

DEFINE DIETS

In this Step, the ***diet for each receptor*** and the receptor-specific ***ingestion rates*** are entered for the higher order species. The prey items and the information required to generate prey item concentrations was entered in Step 3.

First, highlight a ***receptor.*** Inputs apply only to the highlighted receptor.

Enter species-specific ***ingestion rates*** for all applicable media (soil, sediment, water, air, food).

Exposure is partitioned by the percent of each item in the diet. It is assumed that soil and sediment ingestion rates were calculated based on percent soil in diet outside SEEM. The diet items that appear in this Step were entered in Step 3. For each receptor, the sum of diet item percentages must equal 100%.

Ingestion rate references may be entered at the bottom of each page and will be carried through to the output report.

Repeat for each receptor

NOTE: The information for each receptor is active and may be edited when that receptor's name/row is highlighted.

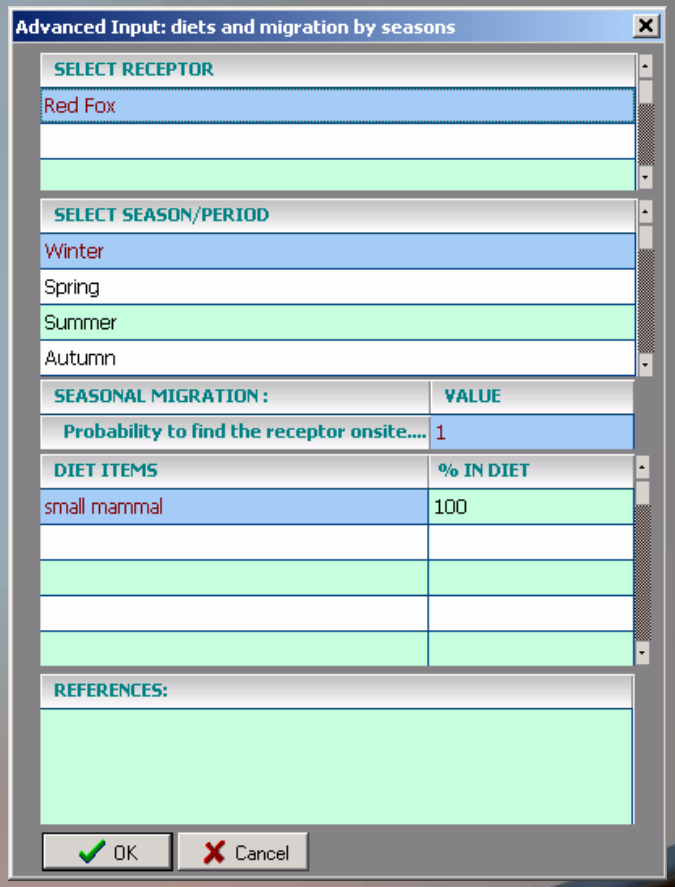
Advanced diet and migration input

Back | Next | Finish | Help

Model Operation

Guided Input Step 5: Define Diets – Advanced Features

- Seasonal exposure modification through onsite probability
- Modify diet composition (%) by seasons



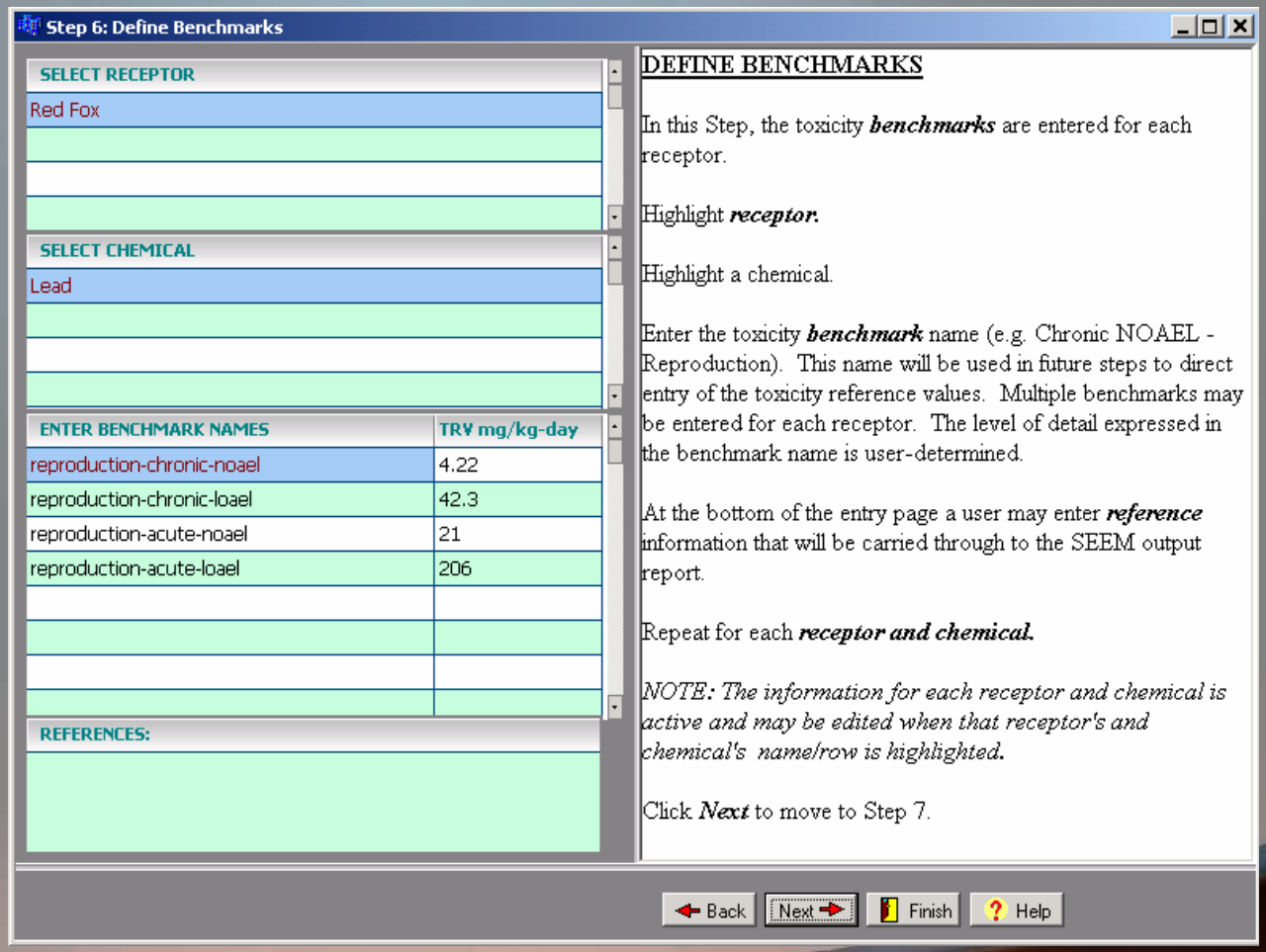
Model Operation

Guided Input Step 6: Define Benchmarks

- Hazard quotients are the primary risk estimation tool employed by SEEM
- A dose is divided by a toxicity reference value
- In this step, the names of the benchmarks are entered
- Name format is user-specified: e.g. Chronic NOAEL – reproduction or simply NOAEL
- For each benchmark, enter a toxicity reference value which is species- and chemical-specific
- May be retrieved from the Terrestrial Toxicity Database (TTD)

Model Operation

Guided Input Step 6: Define Benchmarks



Model Operation

Guided Input Step 7: Define Study Areas

- User's import a base map (number of available formats)
- The scale of the map is set by entry of distance in the East-West and North-South directions
- Click on "Draw Site Areas" to define chemical and habitat suitability polygons

Model Operation – Data Requirements

Step 7: Draw Site Areas Button

- Chemistry polygons are drawn by the user around areas of similar chemistry
- In Step 7 – polygons are drawn, but concentrations and HSI's are entered in Step 8 and Step 9 respectively
- Unique set of chemistry polygons for each chemical and unique set of habitat suitability polygons for each receptor and medium

Model Operation

Step 7: Draw Site Areas Button\Polygon Tool

- User's define two groups of polygons
  - Site Chemistry – by medium and chemical
  - Site HSI – by species/medium
- Polygon's may overlap allowing assignment of site background concentrations
- Each polygon within a group assigned user-specified ID

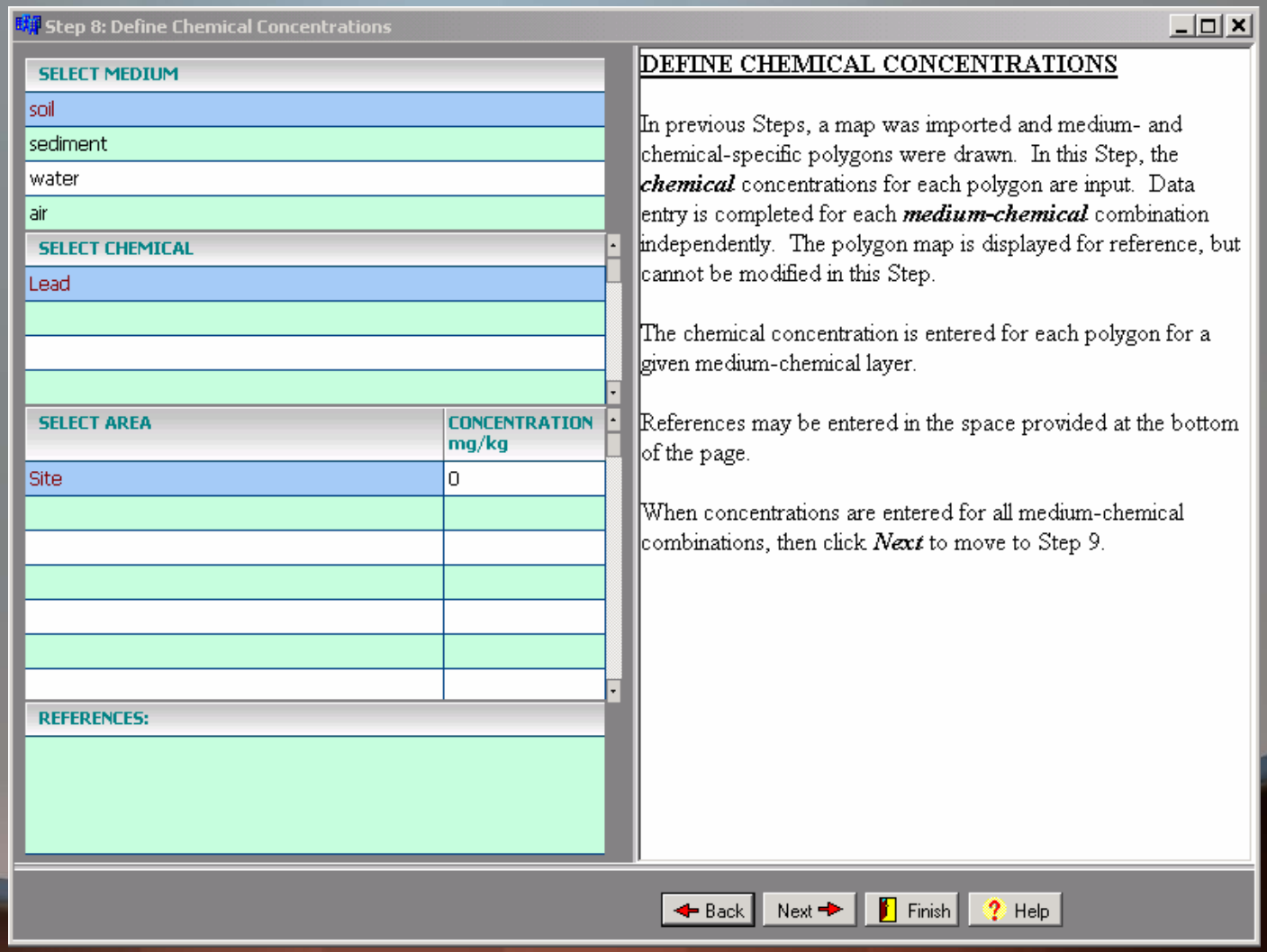
Model Operation

Guided Input Step 8: Define Concentrations

- Enter chemical concentrations for all media (excluding biota)
- Entry by polygon (for reference, click on an area name to view a pop-up of the polygon map)
- A single value entered for each polygon-chemical-medium combination (averaging/statistical analysis by polygon occurs outside of SEEM)
- Each polygon map is chemical- and medium-specific

Model Operation

Guided Input Step 8: Define Concentrations



Model Operation – Overview of Inputs

Habitat Suitability

- Habitat Suitability Index is a compilation of measurable parameters representing a species habitat preference
- SEEM will utilize habitat suitability index –based Habitat Suitability Database (HSD) in ARAMS
- HSI could be user-defined
  - Three levels (low, med., high; 1, 5, 9, respectively)
  - Agreed on through professional judgment.

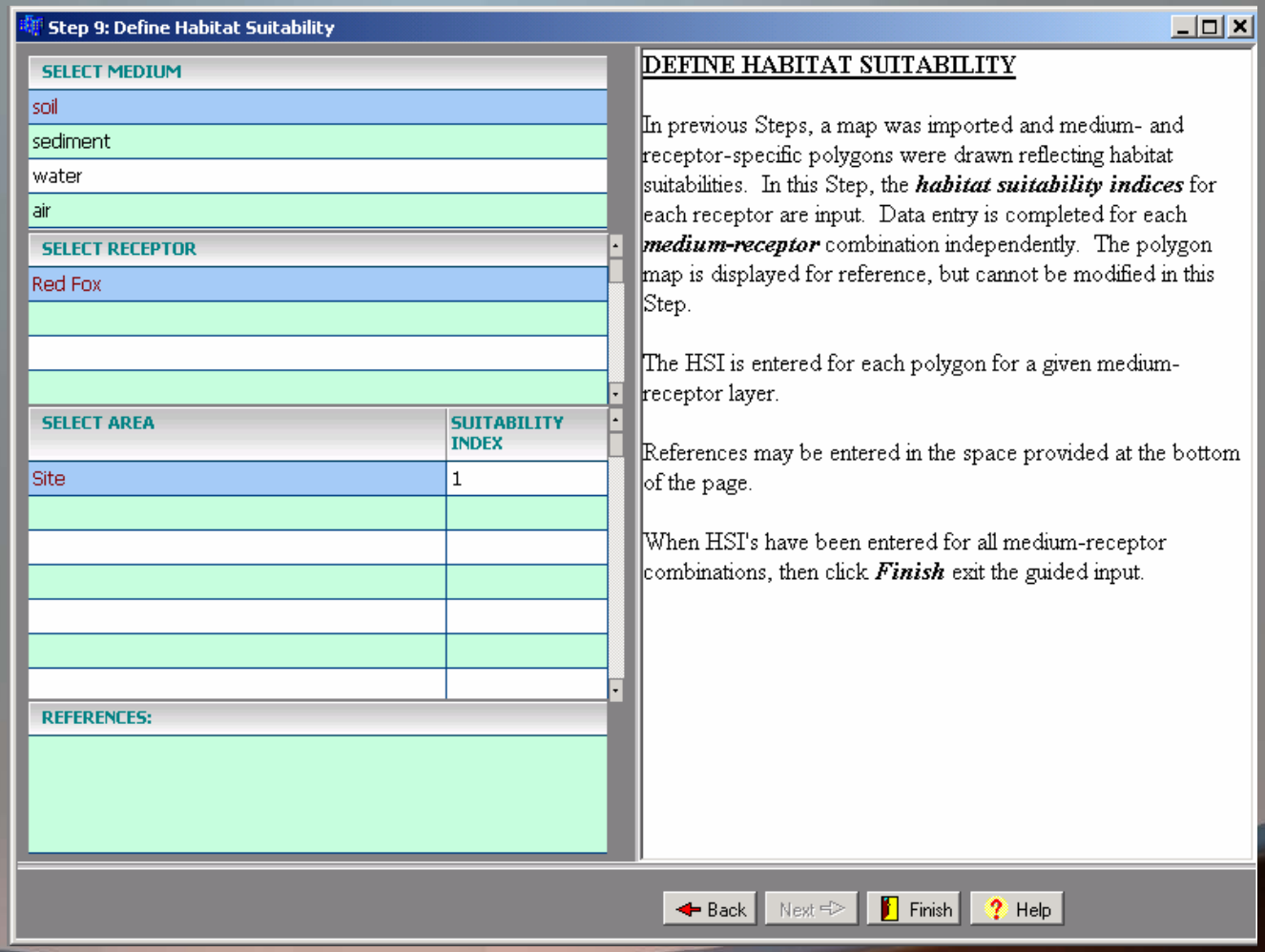
Model Operation

Guided Input Step 9: Define Habitat Suitability

- Enter habitat suitability indices
- Entry by polygon (for reference, click on an area name to view a pop-up of the polygon map)
- Habitat HSI weighting determined through user input of field data through HSI Database; single HSI value per polygon
- Polygons are species-specific
- Will establish direct link to HSD for HSI calculation

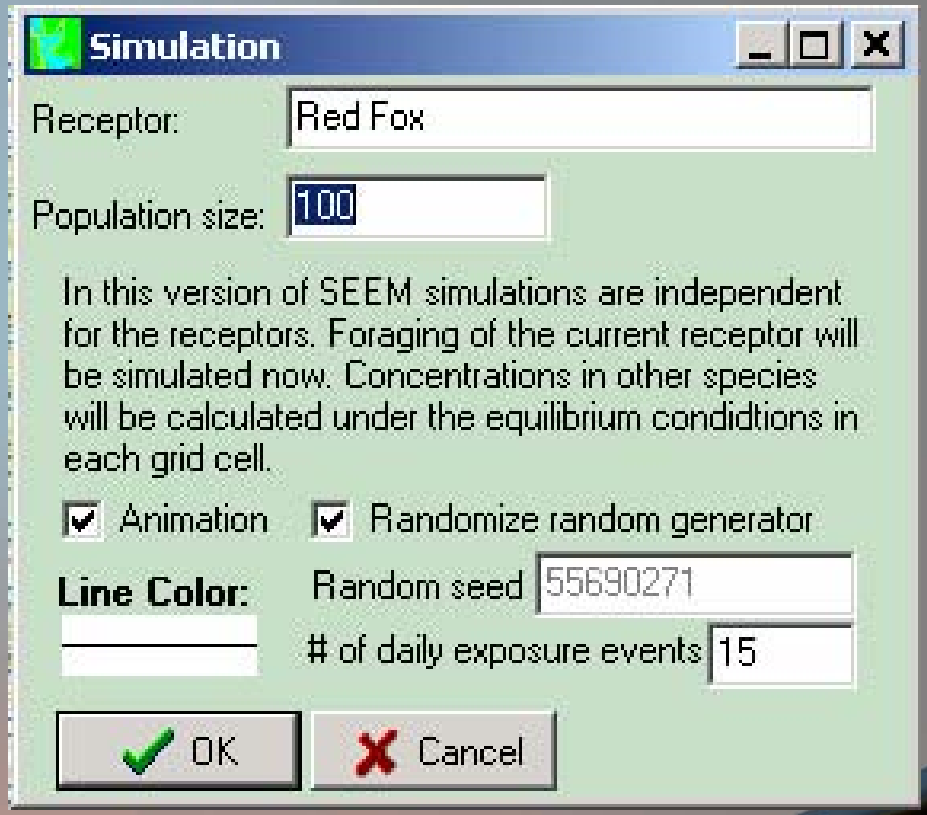
Model Operation

Guided Input Step 9: Define Habitat Suitability



Running The Model

- Specify population size
- Select the number of exposure events within each foraging radius per day



Overview of Model Operation

Important Considerations

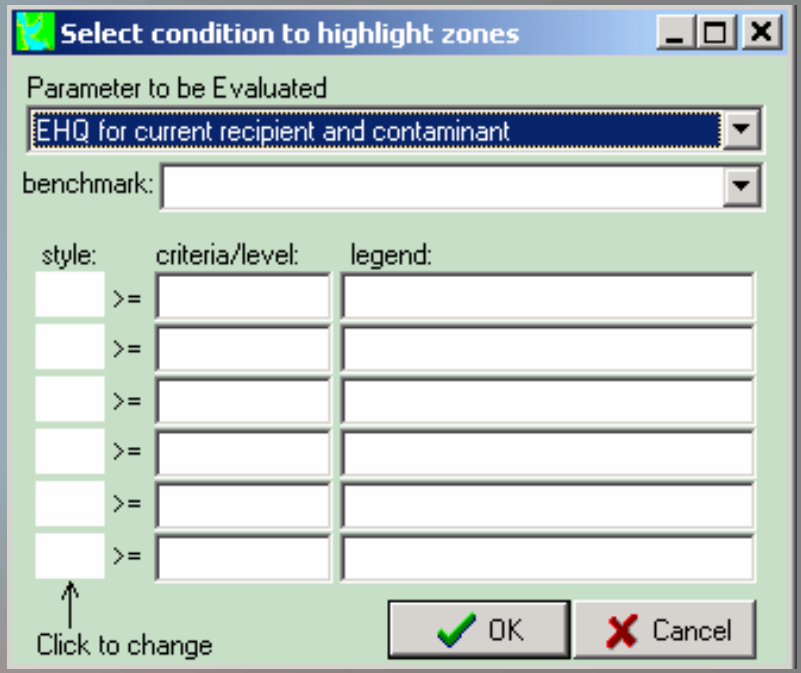
- Model runs are specific to a receptor type
- Model runs are specific to an individual chemical

From: USFWS – J. Leupold

Overview of Model Operation

Spatial visualization Tool

- Map-based highlighting of results
  - Shows where the risk is
- Use to answer “what if..” questions



Overview

Output/Report: Summary of Inputs (Sample: Tables)

SEEM MODEL REPORT
Summary of Model Inputs
Continued-

Chemical Evaluated	
Species Evaluated	

PREY/DIET COMPONENT INPUT DATA

Prey or Diet Component	Bioaccumulation Estimate			
	<BAF or Measured>	<VALUE>	<UNITS>	<SOURCE/REF>
	<BAF or Measured>	<VALUE>	<UNITS>	<SOURCE/REF>
	<BAF or Measured>	<VALUE>	<UNITS>	<SOURCE/REF>
	<BAF or Measured>	<VALUE>	<UNITS>	<SOURCE/REF>
	<BAF or Measured>	<VALUE>	<UNITS>	<SOURCE/REF>
	<BAF or Measured>	<VALUE>	<UNITS>	<SOURCE/REF>

Prey or Diet Component	% of Item in Diet	
		<SOURCE/REF>
		<SOURCE/REF>
		<SOURCE/REF>
		<SOURCE/REF>
		<SOURCE/REF>
		<SOURCE/REF>

Remedial Decision-Making

What if questions:

- **Evaluate habitat loss tradeoffs – remediate fewer acres of most suitable habitat <u>versus</u> remediate more acreage of less suitable habitat**
- **Examine combination of areas remediated to identify the solution that yields the most risk reduction**
- **Evaluate what life stages and foraging strategies may be most susceptible and tune remedial strategy to meet specific wildlife goals (e.g. is the area prime nesting habitat? Given foraging area size, will remaining habitat be sufficient to support the local population?)**

Validation

- Effects of Lead to Songbirds at Small Arms Ranges – AEC
  - Methods
    - Used SEEM at two small arms ranges
    - Captured breeding birds on site
      - Evaluated blood, feather and food lead content
    - Used food Pb to refine model
    - Used blood and feather Pb to determine sublethal effect level (using literature lab and field data, respectively).
  - Results
    - Moderate risk estimated for edge species that did show borderline high blood/feather Pb levels
      - Eastern Bluebirds
      - Northern Cardinal
      - Wood Thrush
      - Eastern Phoebe