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Improvement, Verification, and Refinement Of Spatially-explicit Exposure Models in Risk Assessment. Spatially – Explicit Exposure Model (SEEM) Demonstration

ESTCP PROJECT NO. ER-0917

Prepared by Dr Mark A. Williams, Health Effects Research Program

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14. ABSTRACT
This project was developed to improve direct testing and refinement of the use of spatial models for wildlife exposure assessments. Past studies focused on whether spatial models could improve the assessment of avian exposures to chemicals in the environment. This study examined the value of spatial models with respect to improving the assessment of small mammal exposures in the environment, and aimed to overcome the disconnect that exists when applying 'spatial considerations' between site-wide averages and an assessment that captures exposures based on species-specific habitat preferences. SEEM model outputs were compared to deterministic risk calculations and directly measured blood-lead based risk calculations to determine if SEEM, increased the reliability of exposure assessment. Three sites were selected (two sites in Maryland and one site in California). For small mammals with comparatively small foraging areas, SEEM was no more predictive than site-wide average-based risk calculations. The results emphasized that if habitat is not heterogeneous at ecologically-relevant scales, then SEEM cannot improve risk estimates. Future work will focus on evaluating small mammal exposures where habitat suitability varies over relevant scales. Additionally, SEEM outputs will be evaluated for large mammals and larger foraging areas. Moreover, the larger ESTCP project accomplished the goals of generating greater awareness of the value of spatial models and training risk assessors and managers on using SEEM. The model was also updated in the course of this project.

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Spatially – Explicit Exposure Model (SEEM) Demonstration
Final Report

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Table of Contents

EXECUTIVE SUMMARY 10
1.0 INTRODUCTION 11
1.1 BACKGROUND 11
1.2 OBJECTIVE OF THE DEMONSTRATION 12
1.3 REGULATORY DRIVERS 12
2.0 TECHNOLOGY 13
2.1 TECHNOLOGY DESCRIPTION 13
2.2 TECHNOLOGY DEVELOPMENT 15
2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY 15
3.0 PERFORMANCE OBJECTIVES 18
3.2.1 OBJECTIVE 22
3.2.2 DATA COLLECTION OVERVIEW 22
3.2.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA 22
3.3 PERFORMANCE OBJECTIVE: EASE OF USE 25
3.3.1 OBJECTIVE 25
3.4 PERFORMANCE OBJECTIVE: DEVELOP A PUBLICATION TO SHARE FINDINGS, MODEL UPDATES, AND CONCLUSIONS REGARDING THE VALUE OF SPATIAL MODELS 26
3.4.1 OBJECTIVE 26
3.4.2 DATA COLLECTION OVERVIEW 26
3.4.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA 26
3.5 PERFORMANCE OBJECTIVE: DEVELOPMENT AND DELIVERY OF MANDATORY DELIVERABLES 27
3.5.1 OBJECTIVE 27
3.5.2 DATA COLLECTION OVERVIEW 27
3.5.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA 27
4.0 SITE DESCRIPTIONS 28
4.1 SITE SELECTION 28
4.2 THE ROD & GUN CLUB SKEET RANGE at ABERDEEN PROVING GROUND 28
4.2.1 SITE LOCATION AND HISTORY 28
4.2.2 SITE HABITAT 29
4.2.3 CONTAMINANT DISTRIBUTION 29
4.3 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94), PATUXENT RESEARCH REFUGE, LAUREL, MARYLAND (Fort George G. Meade) 33

4.3.1 SITE LOCATION AND HISTORY 33
4.3.2 SITE HABITAT 33
4.3.3 CONTAMINANT DISTRIBUTION 34
5.0 STUDY DESIGN 36
5.1 CONCEPTUAL EXPERIMENTAL DESIGN 36
5.2 FIELD SAMPLING 36
5.2.1 STUDY SITES 36
5.2.2 SAMPLING METHODS 37
5.2.3 SAMPLING RESULTS 39
5.3 SEEM MODELING 42
5.3.1 THE ROAD AND GUN CLUB SKEET RANGE AT ABERDEEN PROVING GROUND, MARYLAND 42
5.3.2 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94, FT. MEADE) AT PATUXENT RESEARCH REFUGE, LAUREL, MARYLAND. 45
6.0 PERFORMANCE ASSESSMENT 48
6.1 PERFORMANCE OBJECTIVE: FURTHER VERIFY THE SPATIALLY-EXPLICIT EXPOSURE MODEL (SEEM) RESULTS FOR MAMMALIAN AND AVIAN WILDLIFE 48
6.1.1 THE ROD AND GUN CLUB SKEET RANGE AT ABERDEEN PROVING GROUND, MARYLAND 48
6.1.2 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94, FT. MEADE) AT PATUXENT RESEARCH REFUGE IN LAUREL, MARYLAND 49
6.1.3 BLOOD LEAD ASSESSMENT RESULTS 51
6.1.4 COMPARISON 51
6.2 PERFORMANCE OBJECTIVE: IMPROVE AND REFINE SEEM AS A CONSEQUENCE OF THIS EFFORT 53
6.3 PERFORMANCE OBJECTIVE: EASE OF USE 53
6.4 PERFORMANCE OBJECTIVE: DEVELOP A PUBLICATION TO SHARE OUR FINDINGS, MODEL UPDATES AND CONCLUSIONS REGARDING THE VALUE OF SPATIAL MODELS 53
7.0 COST ASSESSMENT 54
7.1 COST MODEL 54
7.1.1 SEEM MODEL RUN 54
7.2 COST DRIVERS 56
7.2.1 CHEMICAL CONCENTRATIONS 56
7.2.2 HABITAT SUITABILITIES 56
7.2.3 BIOACCUMULATION AND INGESTION RATES 57

7.3 COST ANALYSIS 57
8.0 IMPLEMENTATION ISSUES 60
9.0 REFERENCES 62
APPENDIX A: POINTS OF CONTACT.....66

List of Figures

Figure 2-2: Foraging conceptual approach—free-ranging foraging

Figure 2-3: Foraging conceptual approach—static home-range foraging

Figure 2-4: SEEM output illustrating the difference in modeling conclusions depending on the foraging strategy

Figure 4-1: Natural neighbor interpolation method for APG chemical data

Figure 4-2: Summary of APG lead sampling locations and final lead concentration contours32

Figure 4-3: Ft. Meade base map with chemical concentrations coded from low (dark blue) to high (red)

Figure 5-1: Ft. Meade Range 7 Trap Locations (show as blue colored disk areas on the map)

Figure 5-2: Aberdeen Proving Ground – Edgewood Area trapping sites (shown as green colored disk areas on the map)

Figure 6-1: SEEM Summary figure for *Blarina brevicauda* at APG (for average exposure with chronic high TRV (40.7 mg/kg)

Figure 6-2: SEEM summary figure for *Peromyscus leucopus* at APG (for average exposure with chronic high TRV (40.7 mg/kg)

Figure 6-3: SEEM summary figure for *Peromyscus leucopus* at Ft. Meade (for average exposure with chronic high TRV (40.7 mg/kg)

Figure 6-4: SEEM summary figure for *Clethrionomys gapperi* at Ft. Meade (for average exposure with chronic high TRV (40.7 mg/kg)

Figure 6-5: Comparison of measured demonstration site small mammal blood lead concentrations compared to the critical blood lead level of 18 ug/dl

Figure 6-6: Comparison of risks estimated using the SEEM model and risk calculated using the blood level. Comparison based on hazard quotient comparison (x-axis)

Figure 6-7: Foraging range for a single model run (365 days) for an individual bird

Figure 6-8: Foraging range for a single model run (365 days) for an individual small mammal

List of Tables

Table 3-1: Evaluation of performance objectives

Table 3-2: Model update suggestions and modeler responses from Spatial Model Workshop

Table 4-1: Habitat suitability indices for vole, mouse and shrew at APG

Table 4-2: APG Gun Club lead concentrations

Table 4-3: Habitat suitability indices for vole, mouse and shrew at Ft. Meade

Table 4-4: Ft. Meade lead concentrations

Table 5-1: Blood lead levels from small mammals caught at Ft. Meade

Table 5-2: Blood lead levels from mammals caught at Aberdeen Proving Ground

Table 5-3: Stomach content lead concentrations from small mammals collected from Ft. Meade and Aberdeen Proving Ground (APG)

Table 5-4: Lead analysis results from vegetation collected at capture locations of small mammals collected from Ft. Meade and Aberdeen Proving Ground (APG)

Table 5-5: Foraging radius calculated for each receptor species (APG)

Table 5-6: Foraging radius calculated for each receptor species (Ft. Meade)

Table 7-1: Cost model for setup and running a SEEM for one demonstration site

Table 7-2: Summary of Cost Ranges for SEEM Applications

Acronyms and Abbreviations

AAALAC	The Association for Assessment and Accreditation of Laboratory Animal Care
ACAC	Average Concentration with Area Curve Model
APG	Aberdeen Proving Ground
ARAMS	Adaptive Risk Assessment Modeling System
BAF	Bioaccumulation Factor
BRAC	Base Realignment and Closure Act
DOD	US Department of Defense
EHQ	Ecological Hazard Quotient
EPA	U.S. Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FGGM	Fort George G. Meade
GFAAS	Graphite Furnace Atomic Absorption Spectrometry
GIS	Geographical Information System
GLP	Good Laboratory Practice
HQ	Hazard Quotient
HSI	Habitat Suitability Index
IACUC	Institutional Animal Care and Use Committee
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
LOAEL	Lowest Observed Adverse Effect Level
NOAEL	No Observed Adverse Effect Level
NPL	National Priorities List
PEF	Population Effects Foraging Model

PRR	Patuxent Research Refuge
PTOX	Program in Toxicology of the U.S. Army Institute of Public Health
SEEM	Spatially-Explicit Exposure Model
SWMU	Solid Waste Management Unit
TSCA	Toxic Substances Control Act
TRV	Toxicity Reference Value
UCL	Upper Concentration Limit
U.S. EPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

The Project Team developed this ESTCP Project to more directly test and refine the use of spatial models for the assessment of wildlife exposures. Past studies focused on whether spatial models could improve the assessment of avian exposures to chemicals in the environment. This study examines the value of spatial models with respect to improving the assessment of small mammal exposures in the environment.

When applying 'spatial considerations' between site wide averages and an assessment that captures exposures based on species-specific habitat preferences, it is recognized that a disconnect exists. A key aim is to overcome this by applying spatially-explicit exposure models. Failing to consider properly the spatial aspects of exposure relative to the spatial domain (i.e., habitat) of the particular population, could elicit overly conservative risk assessments, and subsequent risk management decisions. This study compares Spatially-Explicit Exposure Model (SEEM) outputs to deterministic risk calculations and directly measures blood-lead based risk calculations to determine if SEEM increases the realism of exposure assessment. The team selected two sites: 1) The Rod and Gun Club Skeet Range at Aberdeen Proving Ground (APG), MD; 2) The Range 17 Trap and Skeet Site (FGGM 94, Ft. Meade) at Patuxent Research Refuge in Laurel, MD.

Thus, a direct comparison was made with the APG and Ft. Meade sites only. The results indicated that for small mammals with comparatively small foraging areas, where exposure to habitat does not vary over relevant scales, SEEM is no more predictive than site-wide average-based risk calculations. Although not the expected outcome, the results emphasize that if habitat is not heterogeneous at ecologically-relevant scales, then spatially-explicit exposure models cannot improve risk estimates. Future work will focus on evaluating small mammal exposures where habitat suitability varies over relevant scales. Additionally, SEEM outputs will be evaluated for large mammals and larger foraging areas. The previously conducted avian study emphasized that SEEM is a valuable tool for species with larger foraging ranges, and sites with habitat variability at relevant scales.

In addition to completing the demonstration analysis, the larger ESTCP project accomplished the goals of generating greater awareness of the value of spatial models and training risk assessors and managers on using SEEM. The model was also updated in the course of this project.

In summary, SEEM has been developed to increase the realism of wildlife exposure assessment and to improve the analysis of population risk. In general, "population-level" assessments consider the individuals that comprise the "population" within the area of interest. SEEM tracks exposure of all individuals in a local population, rather than attempting to calculate exposure for a single representative individual.

1.0 INTRODUCTION

Interactions among biological entities within the environment occur across varying spatial and temporal scales. Likewise, the spatial and temporal distributions of contamination within the environment affect the degree to which plants, animals, and humans are exposed and how they respond. These interactions can be complex. However, using geographical information systems (GIS) and other exposure models that incorporate spatial considerations, risks can be more accurately and realistically estimated. Moreover, visualizing the spatial scales of the risk estimates for wildlife exposures across contaminated sites allows for a clearer understanding of the problem. The present study describes a method to test exposure, and hence risk predictions, using a terrestrially-based, spatially-explicit exposure model called Spatially-Explicit Exposure Model (SEEM); a parallel report focuses on testing exposure with FishRand (FR) – a model that estimates body burdens of organic compounds in fish. Both models incorporate habitat suitability and contaminant heterogeneity.

Using ecological hazard quotients (EHQs), SEEM output is compared to both blood lead and deterministic based EHQs. The assumption is that the directly measured risk of blood lead is the most realistic of the three approaches and that the deterministic approach is the most conservative. Therefore, we judge the use of SEEM in small mammals to be a success if the EHQ for the SEEM model is ten times less than the EHQ for the deterministic approach. Thus, the success of SEEM is dependent on its risk estimates more closely tracking the blood lead risk as compared the deterministic estimate. A ten-fold improvement will be considered successful when comparing the SEEM model and conventional results of blood lead-based toxicity.

1.1 BACKGROUND

Environmental risk assessments for fish and wildlife currently use a simplified method to estimate exposure and risk to valued receptor species. This method relies on a site-wide estimate of chemical concentration (e.g., 95% upper confidence level [UCL] on the average concentration of soil lead) to yield a single, deterministic species-specific estimate of risk (i.e., HQ) for each substance of concern. However, chemicals in the environment are rarely distributed in uniform concentrations. Additionally, interactions of wildlife species within the environment occur in biased, heterogeneous ways, often directed by habitat preferences. Similarly, fish may forage selectively in particular habitat areas, or alternatively, may undergo wide migrations that encompass both areas of contamination and “background” areas. Since chemical distributions are heterogeneous and wildlife exposures are influenced by habitat type and quality, it is apparent that estimates of exposure using a single site-wide soil concentration for each chemical with no consideration of habitat preferences will not accurately capture true exposures on a site. Moreover, the site-wide HQ is not a population metric, and there are limitations to the HQ approach eliciting a binary value that provides little information on the magnitude of risk. These stem from uncertainties in both the numerator (i.e., an estimate of dose or exposure level) and denominator (i.e., the toxicity reference value or TRV) on calculating the HQ. Moreover, “the HQ is a measure of a level of concern only and not a metric of risk” (Tannenbaum *et al.*, 2003). Though the deterministic approach is relatively simple and likely protective from an environmental health perspective, few data have shown it to be reflective of the exposures and associated risks actually experienced by the population at the site.

The disconnect in 'spatial considerations' between the site wide average and an exposure for a habitat limited species is very concerning, particularly when preferences for habitat type are not adequately addressed. By failing to consider properly the spatial aspects of exposures relative to the spatial domain of the particular population, this approach could elicit overly conservative risk assessments, and subsequent risk management decisions. For example, if remediation is the management goal, then it is possible that critical habitat can be destroyed if a site-wide average is used. Spatial models are used to achieve a more refined estimate of exposure that considers the nature of the species as well as the distribution of the contaminant. Generally, a consideration of habitat preferences is absent from ecological risk assessments, though proposed by many to improve estimating exposure to wildlife (Freshman and Menzie 1996; Hope 2000, 2001; Wickwire *et al.* 2004). In order to provide an option that is straightforward, accessible, and begins to capture habitat and foraging behaviors as influences on exposure, SEEM was developed. An integral consideration of this SEEM demonstration, is the potential for greater accuracy and realistic risk estimates, which will have the capacity to improve remedial decision-making should this approach demonstrate benefits of SEEM. In addition, through iterative application, SEEM provides a valuable tool for data and risk exploration, which has the potential to create efficiencies in the risk communication and management process.

1.2 OBJECTIVE OF THE DEMONSTRATION

SEEM has been updated and tested routinely over the past 5 years. In 2006-2007, SEEM was tested on several species of songbirds at two small arms DOD sites (Aberdeen Proving Ground, MD and Ft. McClellan, AL). The results of SEEM were compared to deterministic methods and with direct field observations with the conclusion that SEEM was more predictive than the deterministic methods (Johnson *et al.*, 2007). To be more widely accepted by the risk assessment community, SEEM needs to be further verified using field results; this is the overall goal of the project. Although SEEM has been used to evaluate avian exposures, it has not been tested with small, less vagile species such as voles, mice and other small rodents. This demonstration focuses on small mammal exposures to determine if SEEM more accurately predicts risk from lead exposure compared with the single deterministic HQ method. The field validation metric is blood lead concentrations of small mammals captured at the site and compared with a blood lead TRV derived from the literature. Additionally, we were not permitted to collect samples at Ft. Baker. Although Ft. Baker was initially chosen, this site was later rejected because we could not gain permission from the property owners (the National Park Service) to conduct the field work. Consequently, a direct comparison was made with the APG and Ft. Meade sites only.

1.3 REGULATORY DRIVERS

Federal guidance recognizes the need for the assessment of populations of species, assessment of habitats, and the heterogeneity of contamination (U.S. EPA 1997; 1998). An understanding of how individuals experience contamination in the environment is critical in predictive ecological risk assessment and is required as outlined in EPA Guidance (U.S. EPA 1998). This approach is also consistent with DoD Technical Guidance (U.S. Army BTAG, 2002a; 2002b; 2005a; 2005b). While spatial models are not specifically required by regulation, their inclusion enables ecological risk assessments to be considerably more comprehensive.

2.0 TECHNOLOGY

A conceptual description of SEEM is provided in the bulleted list below. In addition, four published papers provide details on the development and application of SEEM (Johnson *et al*., 2007; von Stackelberg*et al*., 2005; Wickwire *et al*., 2004; Wickwire and Menzie, 2003).

2.1 TECHNOLOGY DESCRIPTION

SEEM has been developed to increase the realism of wildlife exposure assessment and improve the analysis of population risk. In general, "population-level" assessments consider the individuals that comprise the "population" within the area of interest. SEEM tracks exposure of all individuals[1] in a local population, rather than calculating exposure for a single representative individual. In addition, SEEM increases the realism of the exposure assessment process by incorporating habitat suitability and foraging behaviors at a finer resolution versus considering the entire site.

SEEM is a one-dimensional Monte Carlo model that evaluates variability in exposures to a user-defined group of individuals. It relies on inputs including deterministic bioaccumulation factors, terrestrial food chain ingestion modeling factors, toxicity reference values, habitat suitability and the selection of one of two options for individual foraging strategies – static and free range foraging. The output of SEEM is an EHQ (mean and maximum) for each individual for the exposure period; EHQs are then compiled to arrive at a modeled population – effects curve. Figure 2-1 provides an overall schematic of the model summarizing the inputs and outputs of SEEM. Figures 2-2 and 2-3 provide a conceptual summary of the two foraging strategies modeled within SEEM.

A detailed description of model functionality is provided in the User's Manual for the Spatially Explicit Exposure Model (Version 4.2, April 18, 2013) and in the publications referenced previously in this Section. The SEEM model is populated through a series of steps – an overview of the steps is provided in Figure 2-1. The core model contains to exposure types: free-range foraging and static home range foraging. In the former (Figure 2-2), an individual's daily foraging area (the red circle) moves across the landscape guided by habitat suitability.

The movement engine employs a Markov Chain Monte Carlo approach. Within each daily foraging area, the individual will have a user defined number of exposure events (dots). In contrast, the individual daily foraging area does not move in the static home-range foraging type. The foraging locations within the fixed foraging area (red circle) may change locations each day (Figure 2-3).

1 Typically the number of individuals selected is not tuned directly to an observed number of individuals using an area, but rather the number tends to be large to capture representative exposures over time.

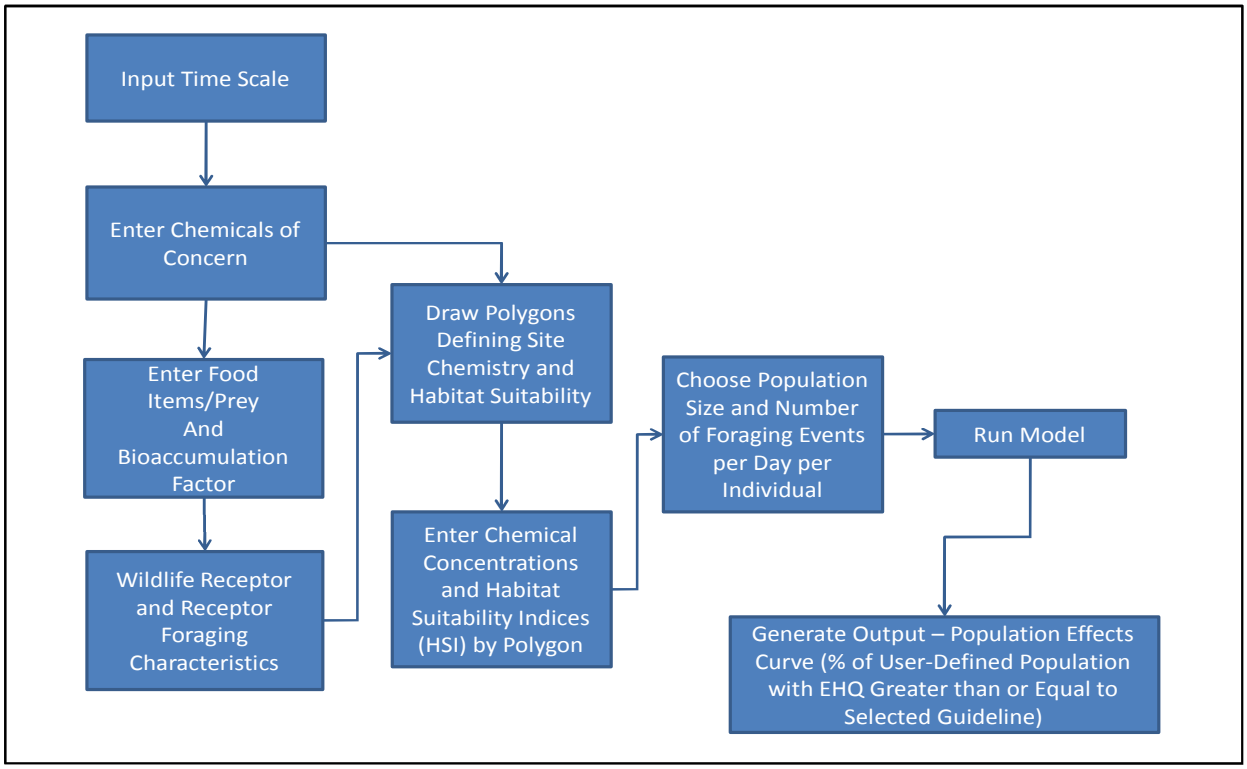


Figure 2-1. Conceptual overview of the SEEM model

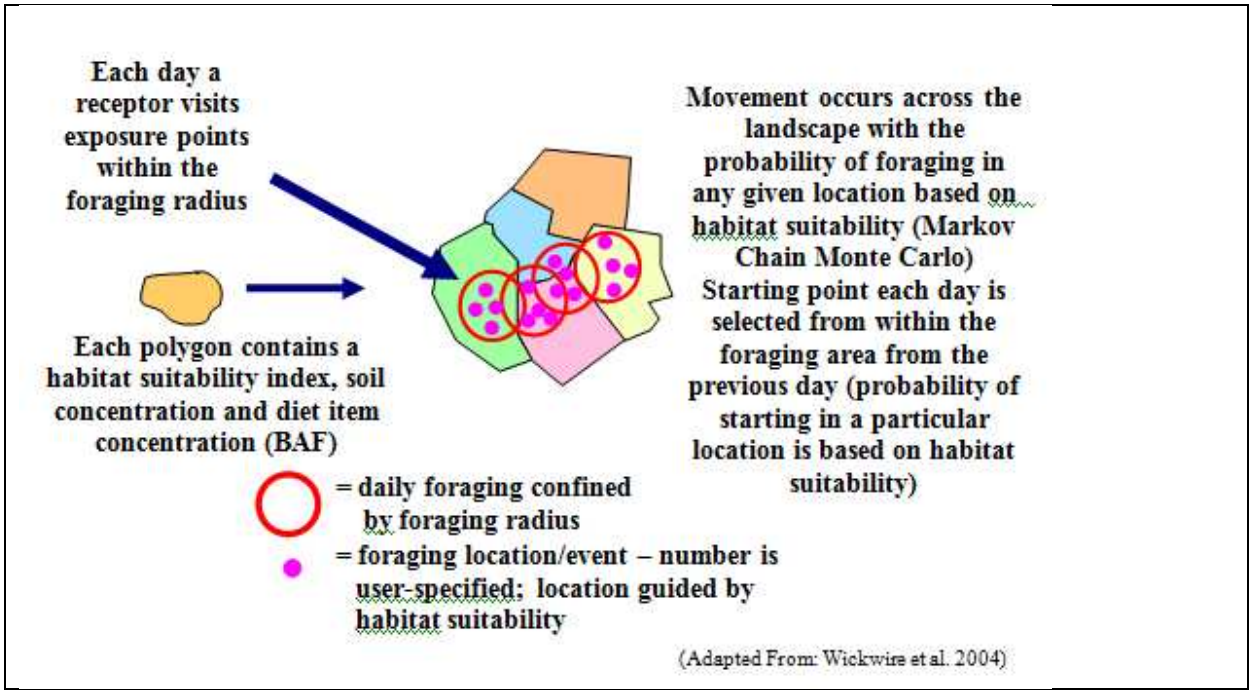


Figure 2-2. Foraging conceptual approach—free-range foraging

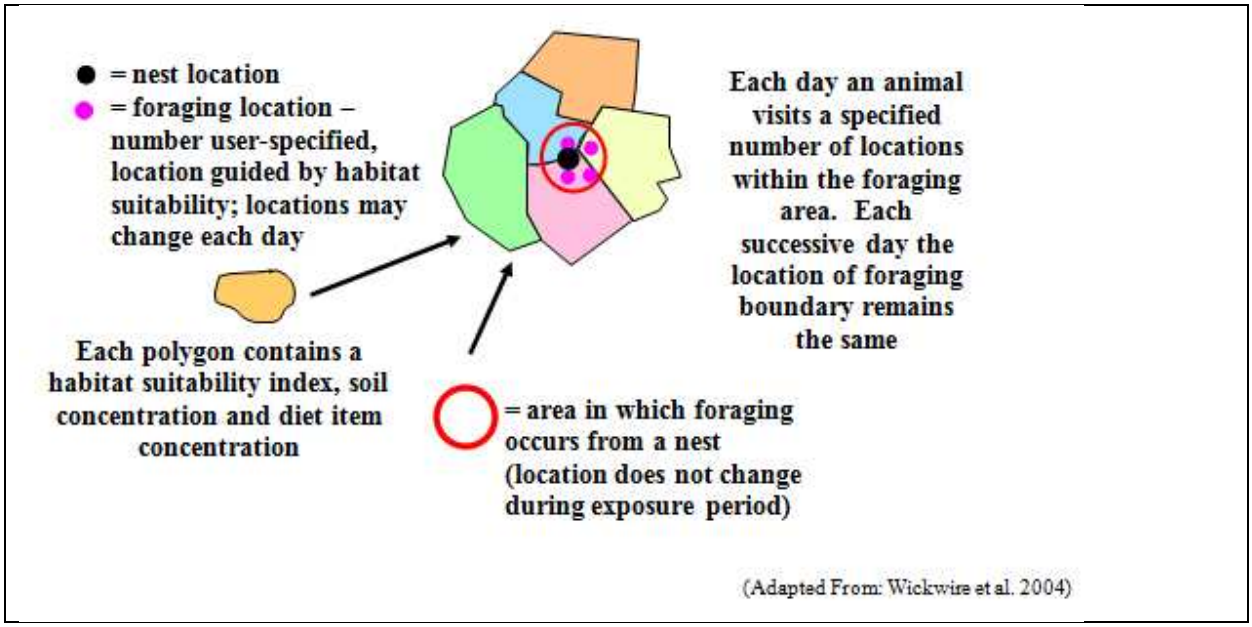


Figure 2-3. Foraging conceptual approach—static home-range foraging

2.2 TECHNOLOGY DEVELOPMENT

SEEM was originally conceptualized based on early work by Freshman and Menzie (1996) and Hope (2000; 2001). The US Army funded initial development in 2003-2004 and has continued to add and modify features since its first development through follow-on Army funding. Funding was provided in 2006-2008 to integrate SEEM into the Adaptive Risk Assessment Management System (ARAMS). In 2008-2009, the US Army, with support from the SEEM development team, led an initial comparison of model outputs to risks determined from direct measures in birds. These early approaches were described in four publications (Freshman and Menzie, *et al.*, 1996; Hope 2000; Hope 2001; Hope 2005).

Each iteration focused on developing a more robust internal guidance, improving the efficiency of the underlying programming, and troubleshooting issues identified by reviewers. The current effort has been developed to validate further and fine tune SEEM.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

This technology provides a number of analytical advantages. While limitations are present, as they are in any model, as long as they are understood within the context of each user's specific modeling goals they can be managed.

The advanatges of this technology include:

- Increasing the realism of terrestrial wildlife exposure assessment by incorporating species-specific foraging areas and habitat suitability indices

- Moving away from selecting the site area or area of contamination as the only spatial context
- Improving the analysis of population risk
- Encouraging use through accessible design and user-determined complexity
- Evaluating life stages and foraging strategies that are the most susceptible and changing remediation plans to meet specific wildlife goals (e.g., is the area a prime nesting habitat?)
- Examining habitat loss tradeoffs – remediating fewer acres of most suitable habitat versus remediating more acreage of less suitable habitat – what combination yields the greatest risk reduction? (Given a fixed foraging size, will the remaining habitat be sufficient to support the local population?)
- Illustrating the importance of life stage in the risk and remedial decision-making process. For example, the outputs in Figure 2-4 are for the same population size and species, but with two different foraging strategies. As discussed in Section 2.1, an individual in a life stage (e.g., juvenile) that employs free-ranging foraging moves across the landscape in search of food. By contrast, an individual who might be nesting for example, would forage close to the nest and move comparatively less. This figure illustrates that in terms of exposure, these two different methods might result in very different conclusions

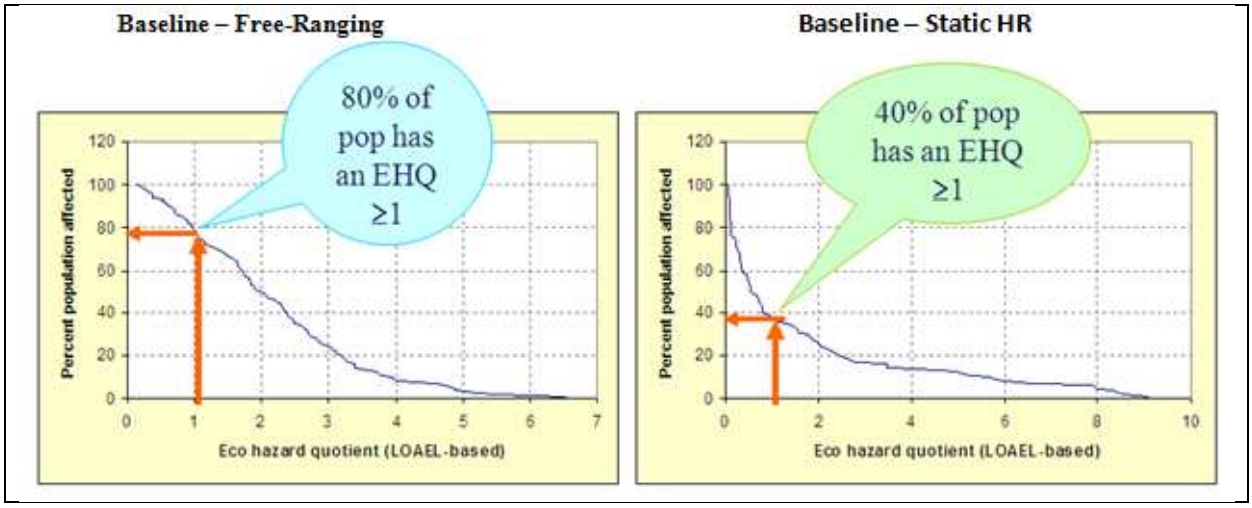


Figure 2-4. SEEM output illustrating the difference in modeling conclusions depending on the foraging strategy

The limitations of this technology include:

- SEEM has value only if the resolution of the foraging receptor and habitat suitability are similar. Modeling exposures of species with comparatively small foraging areas within relatively homogeneous habitat will be no more accurate than the basic site-wide average approach
- A lack of options to evaluate uncertainty with inputs and outputs

- Bioaccumulation options/assumptions are simplified
- The value of the analysis and power are based on the level of effort applied to generating inputs (e.g., are data available for unimpacted soils? Are soil data biased?)
- Habitat suitability can be subjective
- SEEM does not account for dynamic habitats and resulting changes in wildlife usage
- Foraging strategies are overly simplified, lacking important considerations such as competition for limited resources, bioenergetics, and fluctuating food availability
- As a tool, SEEM is only as good as the inputs and requires users to understand the limitations. While no model can account for every dynamic in ecological systems, the assumptions and power of SEEM are clearly defined and summarized in the help materials
- Populating SEEM, even at the most basic level, is more labor and resource intensive than the deterministic approach. This added effort is balanced with the added value of SEEM outputs as compared to deterministic outputs

3.0 PERFORMANCE OBJECTIVES

The effectiveness of SEEM will be determined by its consistency with previous findings and with the similarity of modeled mammal exposures with those that are directly measured.

Table 3-1. Evaluation of performance objectives

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Further verify the SEEM results by evaluating the model utility for small mammals. NOTE: previous work focused on testing the model with avian species. This project extends that work to small mammals.	Soil lead concentrations, blood lead concentrations in mammals, acid-insoluble ash content of feces (to estimate soil ingestion), location and mapping of nest /burrow/den site location and characteristics.	Consistency of modeled exposure estimates with those directly measured. Although the analysis did not indicate that the model results tracked the directly measured risk estimates, the study emphasized the need to consider the unique characteristics of the target receptor and the habitat under review.	For small mammals, the SEEM model outputs tracked closely to the deterministic risk estimates, and not the blood lead measurements. This was in contrast to birds, because of the small size of the foraging area of small mammals and lack of habitat heterogeneity at the foraging scale. This resulted in consistent small mammal exposure through time and space.

Performance Objective	Data Requirements	Success Criteria	Results
Improve and refine SEEM because of this effort.	Feedback from peer reviewers and workshop panelists.	Favorable feedback regarding refinements.	The workshops provided an opportunity for experts to discuss the use and value of spatial models. The other workshop focused on instructing new set of users, as well as requesting student feedback. Both workshops yielded valuable feedback and led to program updates and publications focusing on the value and application of spatial models. Many applications of the models were discussed at the workshop (e.g., natural resource damage assessment, and land-use planning). For example, SEEM was used successfully at the Eureka Mills Superfund Site in Utah (U.S. FWS, 2009) to estimate ecological risks. The data aligned well with life history attributes, and were used in a weight of evidence approach to characterize risk.
Qualitative Performance Objectives			

Performance Objective	Data Requirements	Success Criteria	Results
Ease of use.	Feedback on usability of the model and time required.	Risk assessors and non-risk assessors will be able to learn to apply SEEM.	The workshop included a diverse group including not only risk assessors, but also many project managers who might not traditionally run exposure models. Feedback was positive at the conclusion of the workshop, from which a consensus was reached on spatially explicit wildlife exposure models, and their importance as modeling tools to increase the predictive power of ecological risk assessments, and to improve the process of arriving at risk management decisions.
Develop a publication from the workshop highlighting current thinking on spatial models in risk assessment – applications, benefits vs. risks of using, improvements.	Preparation of the final publication using notes/feedback from workshop participants.	Acceptance for publication in a peer-reviewed journal.	The team published two peer-reviewed articles. Both articles focused on the benefits of spatially-explicit exposure models and described how the models could support a larger set of assessments. In addition, during SETAC 2012 a session was chaired that provided panel talks focused on spatial modeling tools and their advantages.

3.1 PERFORMANCE OBJECTIVE: FURTHER VERIFY THE SPATIALLY-EXPLICIT EXPOSURE MODEL (SEEM) RESULTS FOR MAMMALIAN AND AVIAN WILDLIFE

3.1.1 OBJECTIVE

The effectiveness of SEEM will be determined by its consistency with previous findings, and with the similarity of modeled mammal exposures with those that are directly measured.

3.1.2 DATA COLLECTION OVERVIEW

To evaluate model effectiveness, site-specific data were collected:

- Detailed co-located lead concentrations in surface soils using a Global Positioning System (GPS)
- Lead concentrations in blood from small mammals (adults and young)
- Lead concentrations in food items for mammals
- Species-specific life history information
- Habitat-specific criteria important in assigning Habitat Suitability Index (HSI)
- Blood lead TRV – derived from the toxicological literature

To run the SEEM model, habitat suitability were determined for the representative species and demonstration site locations. This requirement was accomplished using current geographic information system (GIS) maps and estimated by ecologists working at the sites. In addition to the habitat suitability maps, trap site (transects) locations and characteristics were mapped and recorded, as well as burrow and/or den sites, if found.

3.1.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA

Both deterministic and SEEM modeled dose estimates of risk were compared with blood lead levels in adults and young. Success was determined based on how similar SEEM outputs and estimated risks were to directly measured blood lead exposure assessment. The overall goal was to evaluate whether the application of this spatial model was an improvement over application of conventional deterministic methods.

For the evaluation, risk is defined as the comparison between predicted body burdens and no- or lowest-observed effect levels. In this case, risk, is linear with respect to tissue concentrations. Given this assumed linearity, demonstrating better agreement between predicted and observed body burdens (holding all other inputs constant) would by definition lead to better estimates of “bottom-up” risk . Of course, an ecological risk assessment would also consider other lines of evidence not evaluated here. Finding an exposure model that more closely approximates the risk conclusions reached by direct measurement of body burdens could also prove valuable in terms of added flexibility with respect to remedial planning, assessing risk over large areas not amenable to direct measurement, and screening sites early in the assessment process.

While study conclusions do not confirm that the SEEM model closely tracks directly measured exposures for small mammals, they do illustrate the importance of models that are a good fit and

when other approaches might be more appropriate. On reviewing the model outputs, it was apparent that small foraging ranges and comparatively homogeneous habitats in small mammals would result in conclusions similar to a site-wide exposure statistic. It was also observed that small mammals did not move out of the areas in which foraging began. Further assessment of the results is ongoing. Although the performance criteria were not met for this objective, it did add to an understanding of spatial model applicability and will allow for improved application in the future. For example, it is expected that SEEM would work well for larger mammals with broader foraging ranges. Opportunities to test SEEM on larger models are being explored.

3.2 PERFORMANCE OBJECTIVE: IMPROVE AND REFINE SEEM AS A CONSEQUENCE OF THIS EFFORT

3.2.1 OBJECTIVE

The team aimed to conduct workshops that were designed to explore the value of spatial models in general terms, and to determine how best to increase use and acceptance of the models by the scientific community and regulators. Additionally, model improvements will be discussed and prioritized. The workshop focused on collecting insights to four key questions:

1) What are spatially-explicit wildlife exposure models and why are they valuable?
2) How have such models been applied?
3) Are there regulatory impediments to their use?
4)What are the limitations of these models and how could they be improved?

3.2.2 DATA COLLECTION OVERVIEW

A workshop was held in March, 2010, in Menlo Park, CA. Workshop participants (including those from the U.S. Army, U.S. EPA, state agencies, and private sector researchers and consultants, among others), evaluated applications of currently available spatially-explicit wildlife exposure models, and to discuss the use and limitations of SEEM, and to identify and offer suggestions regarding added functionality or refinements of existing components of SEEM.

3.2.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA

Success of these refinements is determined by the feedback we receive with respect to the updates and expanded capabilities. During the expert elicitation workshop that was held in March 2010, feedback was offered to guide refinements of the model.

Although spatially-explicit models had historically found utility in research applications (Loos *et al*. 2010), one of the objectives of the workshop was to enhance their use in regulatory decision-making processes. Recommendations were developed to estimate wildlife exposures. Although there were many applications of the models discussed at the workshop (e.g., natural resource damage assessment, and land-use planning) their applications within the ecological risk

assessment (ERA) process was our major focus in the context of initial screening assessments through remediation with respect to contaminated sites.

For example, SEEM was used successfully at the Eureka Mills Superfund Site in Utah (U.S. FWS, 2009) to estimate ecological risks. This former mining site was subdivided into eight exposure areas, and 23 unique exposure/habitat areas were identified. To support the modelling calculations used by SEEM, Thiessen polygons were used to assign surface soil concentration values to each sample collection point on the site (see Section 4.2.3 below for technical descriptions of the employed algorithms and statistical modeling). In this example, exposure profiles for five songbird species were developed and analyzed. The data aligned well with life history attributes, and were used in a weight of evidence approach to characterize risk.

At the conclusion of the workshop, a consensus was reached on spatially explicit wildlife exposure models, and their importance as modeling tools to increase the predictive power of ecological risk assessments, and to improve the process of arriving at risk management decisions. Additionally, participants agreed that model developers had not yet succeeded in attracting broad acceptance and application of SEEM, and other similar models. However, it was expected that by enhancing model visibility in both regulatory and risk assessment settings, opportunities would be identified and exisiting models like SEEM could be more directly focused on end-user's applications and expectations.

In addition, a separate training course was held during April 3-4, 2012 in South Falls Church, Virginia. We introduced the model followed by an interactive question and answer session. Feedback was generally positive and the participants shared a number of suggestions and requests for software updates. As noted in previous updates, during this project cycle, we transferred programming duties to a new programmer; he original programmer is no longer working on this project. As a result, considerable programming time was spent upgrading the components and troubleshooting any resulting program issues that appeared after the upgrade.

We also provided additional explanation of functionality and limitations of the model. The most noticeable update was the addition of an Excel tool, SEEM XL, which allows a user to export an existing SEEM model file (.MDL) to Excel for an improved QA/QC environment where changes can be made. The tool is described in greater detail below. Table 3-2 summarizes the model update requests from the training participants and the response of the development team.

Table 3-2. Model updates suggestions and modeler responses from the Spatial Model Workshop

Identified Potential Update	**Developer Response**
Rename 'population size' – misleading and potentially problematic when dealing with regulators – it is actually the number of model simulations or model runs – rename in model and add explanation to user guide.	The name was changed to reflect more accurately that the number is user defined. The revised title is the 'Model Population Size'.
Change ellipsis to ellipse.	The adjustment was completed and the different drawing functions were reviewed.

Identified Potential Update	Developer Response
Confirm what each drawing tool type does.	Completed
Check on fraction in diet for soil – confirm if use percent of food ingestion that the food ingestion rate is adjusted as well so total intake equals 100 – confirm what the model does and then Ted will discuss to confirm that is the correct way.	We confirmed that soil ingestion is a percentage of food ingestion in the model.
Check on polygons that extend outside of the image in the jpeg – smaller than the screen.	This reflects the nature of image processing and the limits of the graphical display in the model. SEEM uses a grid-based calculation platform with a fixed number of cells – 25 x 25. To increase user accessibility to the model, however, users may draw polygons to define habitat suitability and site chemistry. These defined polygons are then translated into fixed grid cell values using an area-weighted average to arrive at a value for each cell. Users import an image into SEEM and the edge of that image may not directly align with the edge of the map – often there is a border around the image. Therefore, grid cells may appear to extend off the map.
Check on polygons that extend outside of the image in the jpeg – smaller than the screen.	This is a graphical limitation. The foraging area circles define a fixed area so if they are located near the edge of the map, they will extend beyond the graphic boundary. However, foraging will only occur where the HSI>0 to the image boundary and not in areas beyond the image. See the comment above regarding the image boundaries.
Emphasize population size and model runs = for example 20 individuals 10 run, versus 200 individuals for 1 run.	Additional explanations have been added to the User Guide.
Is there any way to download the paths (x, y coordinates) that the individuals follow in a run?	An advanced user tool may be used to download paths of individuals via GIS. However, it is not designed for non-GIS programmer use.
Is there a limit to the number of model runs?	Limitations in computing speed and Excel cells will limit the number of individuals and/or days that one can select. A user can actually run the model as many times, as he/she wishes, but as the number of individuals and/or the number of days the model is run increase, model efficiency will decrease.
Can we add summary statistics to the output table (mean, median, mode, 95th UCL, max, min on the page with the output table by individuals)?	Automating this functionality would require more programming than feasible for this round of updates and the programming would be external to the core model. The output report is generated in Excel worksheets to facilitate the use of user-preferred statistical software to characterize the outputs.

Identified Potential Update	Developer Response
Can we remove the underlying grid (25 x 25 cells) – it can be confusing when polygons are smaller than a cell? Prefer to work directly from polygons (pixels) rather than translating polygons to the grid.	The grid has been in place from the beginning of model development. It is a standard approach and would require reworking the entire model to remove. However, we are working on a GIS add-in that allows the user to specify the grid size increasing the resolution depending on the resolution of the site data.
Pull down menu to jump to any guided input step from any guided input step.	Currently the forward and back arrows are used to navigate the input screens. In the future, we will explore opportunities to modify data entry.
Expand the Draw Sites screen (but may account for this through the GIS tool).	Because the long-term goal is to migrate to a GIS platform with much greater flexibility, we are limiting the more time-intensive updates to the standalone SEEM.
Allow the use of an equation for BAF (ideally a distribution, but an equation would be a good step) – we might be able to do this in the Excel Tool.	The SEEM XL tool allows users to link equations into the input cells for the model. However, this does not allow for the use of distributions for inputs. To assess distributions of input, users will need to run the model under specific scenarios varying the inputs.
Add link to HSI models to the User Guide.	This link was added.
Add further discussion about the translation to matrix cells and that some foraging areas will extend into areas where HSI = 0 because there is a cell that is in play.	This has been discussed in a previous response to comments.
Sometimes changed inputs and moved forward, then back, the values will revert to 0 – attempted to return, tab between entries, save, etc. – was unpredictable – sometimes it will save, other times not. No error messages.	When updating the core software, which must occur periodically, some glitches may appear. When they are repeatable, we can review and in many cases resolve the issues. However, some issues are not easily replicated and therefore very challenging to identify. We have made every effort to create as stable a platform as possible and, when time and budget allow, make every effort to remedy user-defined issues that can be tracked and described in detail.

3.3 PERFORMANCE OBJECTIVE: EASE OF USE

3.3.1 OBJECTIVE

It has been an important goal of this project from the outset that SEEM be accessible to a wide range of users. The value of these models is their power to test theories, identify trends, and run repeatedly under different scenarios.

3.3.2 DATA COLLECTION OVERVIEW

Comments received during the workshop, and from other users, as well as clarifications in the User Guide were used to increase ease of use.

3.3.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA

Both the model and the user manual were updated. Success of these refinements will be determined by feedback and the ability of risk and non-risk assessors to access the model in the future. We encourage open communication from users and will seek input when possible.

3.4 PERFORMANCE OBJECTIVE: DEVELOP A PUBLICATION TO SHARE FINDINGS, MODEL UPDATES, AND CONCLUSIONS REGARDING THE VALUE OF SPATIAL MODELS

3.4.1 OBJECTIVE

Develop a publication from the workshop emphasizing the current thinking on spatial models in risk assessment – applications, benefits, risks, and improvements.

3.4.2 DATA COLLECTION OVERVIEW

Preparation of the final publication using notes/feedback from workshop participants.

3.4.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA

Success of the performance objective is acceptance of model results for publication in a peer reviewed journal. Two articles have been recently published focusing on the future applications and the use of spatially-explicit exposure models (Wickwire *et al.*, 2011; Hope BK *et al.*, 2011).

In addition, we chaired and organized the following session at SETAC 2012[2]: Spatially-Explicit Wildlife Exposure Models: Moving Toward Their Increased Acceptance and Use. Chairs: Mark Johnson and Ted Wickwire. The following presentations were given by the Project Team at SETAC in 2012:

- M.S. Johnson, M. Quinn, and T. Wickwire. 2012. Improving risk predictions through the integration of space and habitat suitability: an application of the spatially-explicit exposure model (SEEM). Presented in Session: Wildlife Ecotoxicology Supporting Management Decision Making at SETAC North America 33rd Annual Meeting, Long Beach Convention and Entertainment Center, Long Beach, California, 11–15, November 2012
- M. Quinn, M.S. Johnson and T. Wickwire. 2012. Kicking the tires: corroboration of model output with field data of the spatially-explicit exposure model (SEEM). Presented in Session: Spatially-explicit Wildlife Exposure Models: Moving Toward Their Increased Acceptance and Use at SETAC North America 33rd Annual Meeting, Long Beach Convention and Entertainment Center, Long Beach, California, 11–15 November 2012

2 North America 33rd Annual Meeting, Long Beach California, Long Beach Convention and Entertainment Center, Long Beach, California, 11–15 November 2012.

- M.S. Johnson, B. Hope, and T. Wickwire. 2012. Spatially-explicit Wildlife Exposure Models (PANEL): Moving Toward Their Increased Acceptance and Use. Presented in Session: Spatially-explicit Wildlife Exposure Models: Moving Toward Their Increased Acceptance and Use at SETAC North America 33rd Annual Meeting, Long Beach Convention and Entertainment Center, Long Beach, California, 11–15 November 2012

3.5 PERFORMANCE OBJECTIVE: DEVELOPMENT AND DELIVERY OF MANDATORY DELIVERABLES

3.5.1 OBJECTIVE

Includes documents heretofore not submitted for review that are part of the funding requirement (i.e., Cost and Performance Report and Final Technical Report).

3.5.2 DATA COLLECTION OVERVIEW

Cost and Performance Report is an executive summary of findings and the Final Technical Report is an expanded report of methods, background, results, and discussion. Both require an analysis of both models respective to the success criteria.

3.5.3 PERFORMANCE REVIEW BASED ON SUCCESS CRITERIA

The mandatory deliverables have been completed.

4.0 SITE DESCRIPTIONS

Two sites were identified for the demonstration of SEEM. They include:

- The Rod and Gun Club Skeet Range in the Gun Club Creek Investigation Area (GCCIA) of the Other Edgewood Areas Study Area within the Edgewood Area National Priorities List Site at the US Army Garrison, Aberdeen Proving Ground, Maryland

- The Range 17 Trap and Skeet Site (FGGM 94) located at Patuxent Research Refuge in Laurel, Maryland

4.1 SITE SELECTION

SEEM sites were selected based on the following criteria:

- Well-characterized surface soil data with soil lead concentrations exceeding 10,000 mg/kg in screened soil samples
- Presence of mixed habitat types suitable for rodents and heterogeneous in terms of habitat suitability for target receptors
- Local or DOD knowledge of wildlife usage
- Digital maps available
- Accessible to the research team

With the advantage of having already completed an initial study at two rifle ranges, sustained close proximity of lead and copper from spent copper-jacketed lead bullets in the soil accelerated galvanic oxidation between the two metals. This led to increased lead solubility, and mobility within the environment.

4.2 THE ROD AND GUN CLUB SKEET RANGE at ABERDEEN PROVING GROUND

4.2.1 SITE LOCATION AND HISTORY

The APG Gun Club Creek Investigation site is located within the Edgewood Area National Priorities List Site at the U.S. Army Garrison, Aberdeen Proving Ground, in Aberdeen, Maryland. Chesapeake Bay borders the property. Over the years activities on the site have included research, development, testing and manufacture of materials for chemical warfare (GP, 2009). The site was listed on the National Priorities List (NPL) in 1990. The Rod and Gun Club Skeet Range is east of the demolition debris site and, importantly, the shot fall zone is to the east in the marshes of Gun Club Creek (General Physics Corporation, 2009).

4.2.2 SITE HABITAT

The Virginia Department of Game and Inland Fisheries has a comprehensive database of wildlife species fact sheets. Although the site of interest is located in Maryland, the Virginia information was helpful in determining species to evaluate. Based on this information, three small mammal receptors were selected: the meadow jumping mouse (*Zapus hudsonius americanus*), pine vole (Microtus pinetorum scalapsoides), and least shrew (*Cryptotis parva parva*) in the APG area.

The meadow jumping mouse is found in thin woods, alder thickets, clearings, and weedy thickets along streams, as well as old field grasslands and moist meadow habitats The pine vole can occur in a variety of habitats from deciduous and pine forest to grassy fields. It prefers habitat with well drained soils and thick ground cover of either forest litter or vegetation. The least shrew prefers habitat of open areas such as field and meadows with grassy cover and scattered brush . In summary, the pine vole favors forests, the meadow jumping mouse favors grasslands and low density woods, while the least shrew prefers open areas. Ultimately, the species caught in the traps included the white-footed mouse (*Peromyscus leucopus*), the short-tailed shrew (*Blarina brevicauda*), and the southern red-backed vole (*Clethrionomys gapperi*). The comparisons were completed using these species.

The habitat suitability for each vegetation type was assigned based on best professional judgment combined with information provided by the Virginia Department of Game and Inland Fisheries website (Table 4-1 and Figure 4-2).

Table 4-1. Habitat suitability indices for vole, mouse, and shrew at APG

	Vole	Mouse	Shrew
Northern Tidal Salt Marsh	0.3	1	0.3
Plain Dry and Dry Mesic Oak Forest	1	0.3	0.8
Developed Open Space	0.2	0.2	0.2
Cultivated Cropland	0.2	0.2	0.2

4.2.3 CONTAMINANT DISTRIBUTION

The APG Gun Club lead data came from three different sources:

1. Surface Soil (historical lab) (from 2009 RI report for Gun Club Creek)
2. XRF data (historical lab) (from 2009 RI report for Gun Club Creek)
3. XRF data (collected August 2011)

The lead concentrations associated with the APG Gun Club range ranged from less than 260 to more than 10,000 mg/kg. The number of samples and concentration ranges are provided below in Table 4-2.

Table 4-2. APG Gun Club Soil Lead concentrations

Surface Soil Lead Concentrations	**Number of Samples**
<= 260 ppm (dark blue dots)	97
260-1000 ppm (light blue dots)	16
1000-3000 ppm (light green dots)	9
3000-5000 ppm (yellow dots	4
5000-10000 ppm (orange dots)	4
>10000 ppm (red dots)	3

Since data were derived from three separate sources, the “Natural Neighbor Interpolation” method was used to derive final exposure concentrations for the site (Sibson, 1981; Watson, 1992). Natural neighbor interpolation is a simple weighted moving average technique that uses Delaunay triangulation (Voronoi diagram) to select and weight nearby points to interpolate a value (Sibson, 1981). It is also known as Sibson or "area-stealing" interpolation.

The basic properties of Natural Neighbor Interpolation are that it is local, using only a subset of samples that surround a query point, wherein interpolated heights are guaranteed to lie within the range of samples used. Natural Neighbor Interpolation has many advantages over simpler methods of interpolation, such as Nearest-Neighbor Interpolation , in that it provides a smoother approximation to the underlying "true" function.The interpolation process is illustrated in Figure 4-1 below.

Initially, a Voronoi (Thiessen) diagram is constructed of neighboring polygons for all the sampling points, represented by the olive-colored polygons (Figure 4-1). A new Voronoi polygon, beige in color, is then created around the interpolation point (red star). The proportion of overlap between this new polygon and the initial polygons are then used as the weights.

Predicted value $= \frac{\sum_{i=0}^{n} \mathrm{Area_i} \times \mathrm{Value_i}}{\sum_{i=0}^{n} \mathrm{Area_i}}$ in which, n is the natural neighbors of the interpolation point (red star). N = 1, 2, 3, 4, 6, 8 in the scenario of Figure 4-1 below.

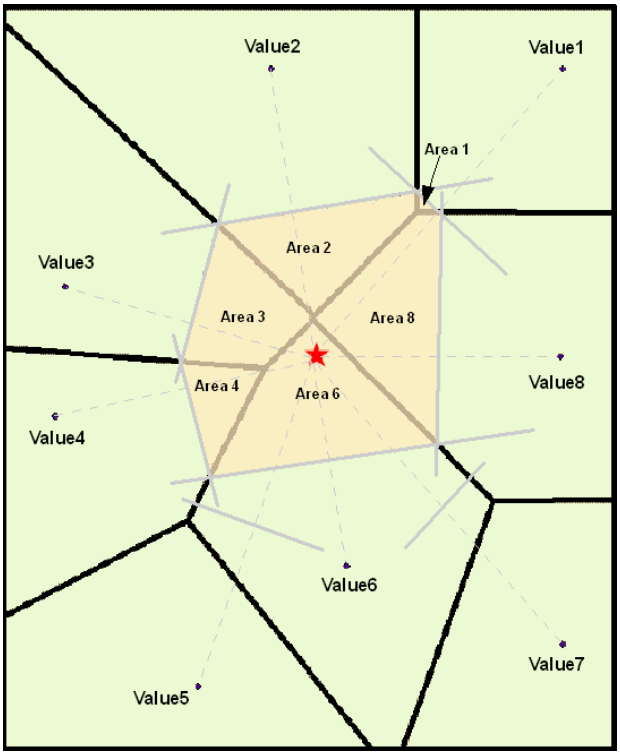


Figure 4-1. Natural neighbor interpolation method for APG chemical data

The natural neighbor tool can efficiently handle large numbers of input points. The interpolated value at any location is a linear combination of all the natural neighbors of that location where the resulting surface is continuous and smooth with minimal peaks and valleys between data. It can also effectively handle the large gaps and nonhomogeneous sample distributions in the APG lead datasets.

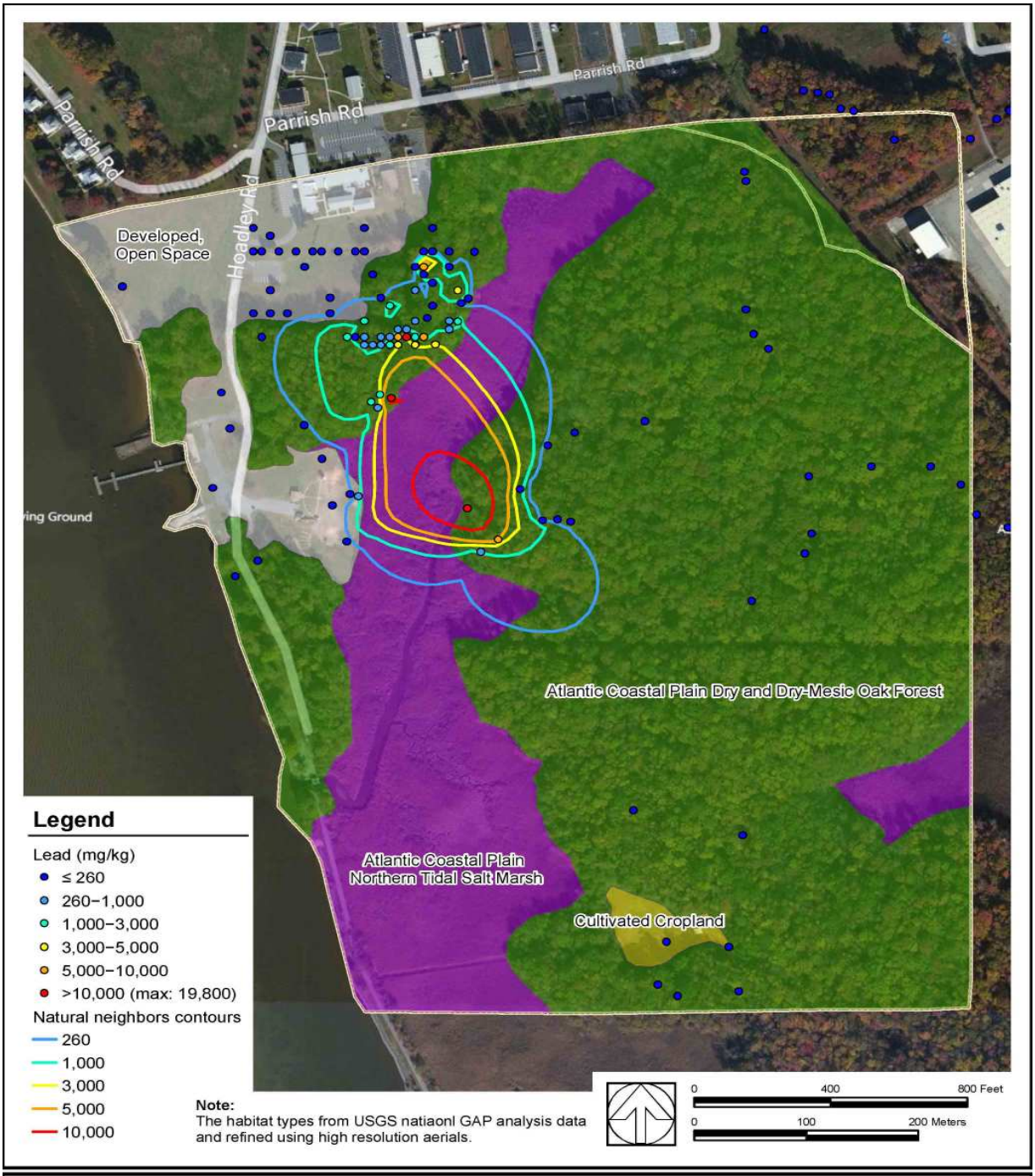
The interpolation uncertainty (standard error) for a location is affected only by the data values and weightings of its natural neighbors.

$$\text{Standard deviation} = \sqrt{\frac{\sum_{i=0}^{n} \text{Area}_i \times (\text{Value}_i)^2}{\sum_{i=0}^{n} \text{Area}_i} - (\text{predicted value})^2} \times \frac{n}{n-1}$$

Standard error = Standard deviation/sqrt(n)

In which, “n” represents the natural neighbors of the interpolation point (red star). N = 1, 2, 3, 4, 6, and 8 in the scenario of Figure 4-1.

The sampling locations and contours that were drawn into the SEEM model are shown in Figure 4-2.



Habitat types and lead concentrations (from Natural Neighbor interpolation) for the Aberdeen Proving Ground demonstration site

Exponent®

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Figure 4-2. Summary of APG lead sampling locations and final soil lead concentration contours.

4.3 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94), PATUXENT RESEARCH REFUGE, LAUREL, MARYLAND (Fort George G. Meade)

4.3.1 SITE LOCATION AND HISTORY

Fort George G. Meade (FGGM) became an active Army installation with an Act of Congress in 1917, and served as an important training location during World Wars I and II, and into the 1960's. In 1988, the facility became subject to the Base Realignment and Closure Act (BRAC), wherein remedial activities were initiated at a number of parcels (FGGM Army Defense Environmental Restoration Program Installation Action Plan, November 2010). One of the areas requiring remediation was the Patuxent Research Refuge (PRR) North Tract, containing a Trap and Skeet Site (Range 17) for FGGM. Because PRR's mission is to conserve and protect wildlife, an assessment of risk to biota inhabiting the site was necessary, as well as to develop clean up goals. The initial investigation of the Trap and Skeet Site began in 2004 (URS 2009).

4.3.2 SITE HABITAT

The Virginia Department of Game and Inland Fisheries has a comprehensive database of wildlife species fact sheets. Although the site of interest is located in Maryland, the information from Virginia is worthwhile for determining which specific species best represent a mouse, vole and shrew. http://www.dgif.virginia.gov/wildlife/information/?t=2.

Table 4-3. Habitat suitability indices for vole, mouse and shrew at Ft. Meade

	Vole	Mouse	Shrew
Small Blackwater River Floodplain Forest	0.3	1	0.3
Plain Dry and Dry Mesic Oak Forest	1	0.3	0.8
Developed Open Space	0.2	0.2	0.2
Evergreen Plantation or Managed Pine	0.4	0.4	0.6
Disturbed/Successional Shrub Regeneration	0.8	0.6	1
Non-riverine swamp and wet hardwood forest - oak dominated modifier	0.6	0.8	0.4
Developed, Low Intensity	0.1	0.1	0.1
Road	0	0	0

The habitat suitability for each vegetation type was assigned based on best professional judgment combined with information provided by the Virginia Department of Game and Inland Fisheries website (Table 4-3 and Figure 4-3).

4.3.3 CONTAMINANT DISTRIBUTION

The soil lead concentrations associated with Ft. Meade Range 17 varied from 44 to 130,000 mg/kg. The samples were divided into five separate categories ranked by concentration from lowest to highest (Table 4-4).

Table 4-4. Ft. Meade lead concentrations

Percentile	Number of Samples	Surface Soil Lead Concentrations (mg/kg)
0–25	26	44–270
25–50	26	270–1,200
50–75	26	1,200–3,000
75–95	20	3,000–20,000
95–100	7	20,000–130,000

The sampling locations are shown in Figure 4-3. Each category was color coded so that polygons could be drawn around each with ease.

Note that the preparation of the soil and habitat data is site-specific and cannot be standardized across sites. In some cases a grid might be used, while in other cases polygons might be drawn by hand. In this case (Figure 4-3), formal interpolation did not occur.

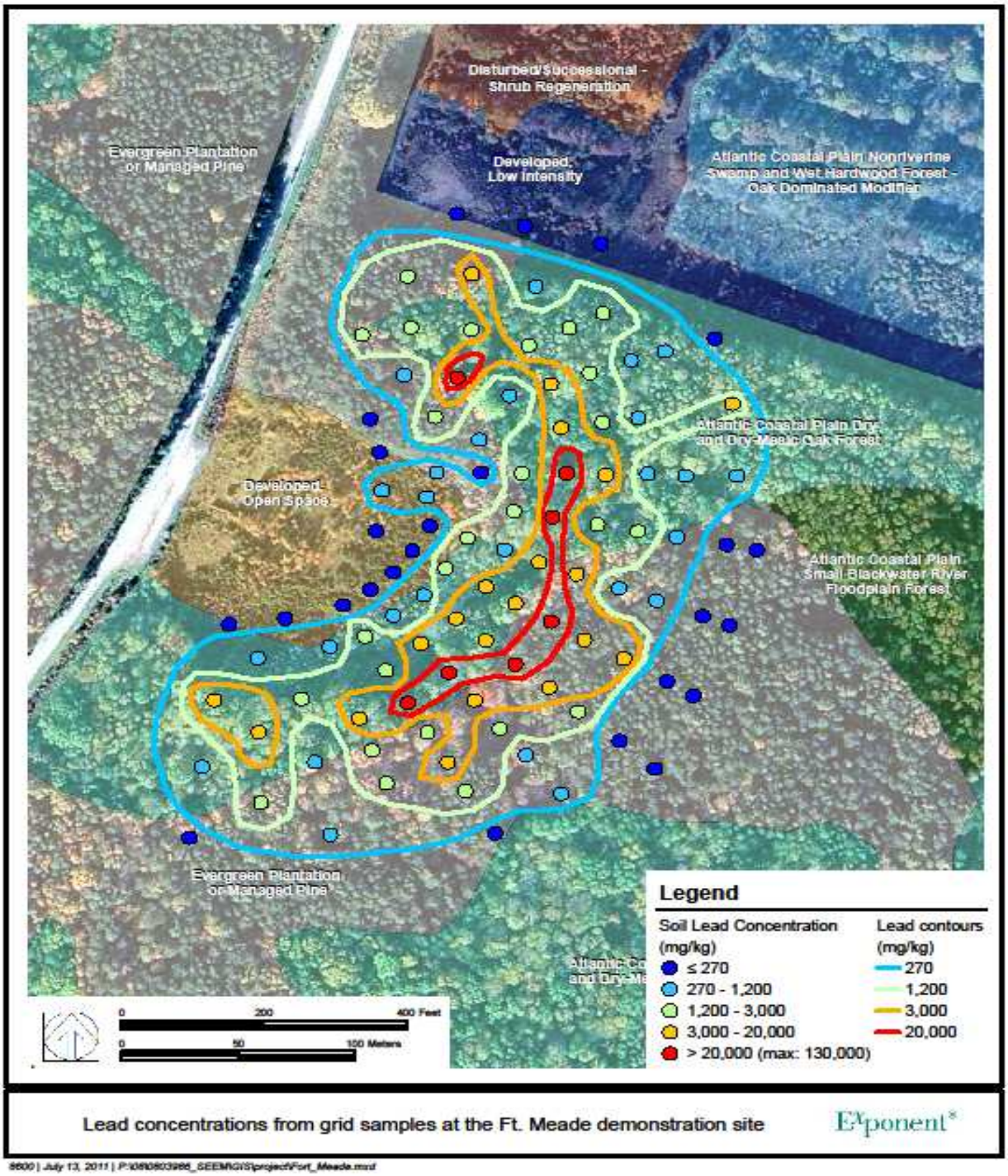

Figure 4-3. Ft. Meade base map with chemical concentrations coded from low (dark blue) to high (red). Note that the concentration groupings are specific to the data at this site.

5.0 STUDY DESIGN

The study is divided into two parts, a field sampling program and an application of the SEEM model. The goal was to compare the results from directly measured lead concentrations in small mammals to the prediction derived from SEEM model runs.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

SEEM was designed to be a model that improves the prediction of wildlife exposure in the absence of directly measured exposures. As with any model development process, an important step is testing how the model compares with respect to direct measurements. In this case, the direct measurement of wildlife exposure examines blood lead concentrations in small mammals. As wildlife forage across a landscape they are potentially exposed to chemicals in the soil or food. SEEM models these exposures and in the process is designed to capture wildlife habitat heterogeneity and preferences more directly than the application of a site-wide exposure statistic. The experiment is designed to compare wildlife habitat heterogeneity and preferences more directly than the application of a site-wide exposure statistic.

5.2 FIELD SAMPLING

5.2.1 STUDY SITES

Fort Meade

The North Tract of Patuxent Research Refuge (PRR), located in Laurel, MD, USA (39.08°N, 76.77°W), encompasses approximately 8,100 acres. A part of the area contains soils that are contaminated with lead on an abandoned trap and skeet firing range (Range 17). Range 17 was originally operated by the U.S. Army at Ft. Meade but later transferred to PRR through the Base Realignment and Closure Act of 1990. Lead has been identified as a contaminant of potential concern at the site based on the historical use of lead shot at this range.

The refuge is situated in the coastal plain of central Maryland and is characterized by gently sloping terrain, typical of a coastal plain, with elevations ranging from near 80 feet in river bottomlands to about 240 feet at the highest elevations. The predominant soil type is Beltsville silt loam. Land use in the watershed is mainly upland or wetland forests, with significant urban and agricultural development. The general habitat or land cover types for uplands are forest (deciduous, pine, or mixed), oak-pine savannah, shrub-early succession forest, and grassland-old field, whereas habitat types for wetlands are floodplain forest and swamp, river and stream, depressional forest and shrub wetlands, and emergent wetlands. Much of the land is now forested is a result of gradual reforestation as lands have been retired from agricultural use.

Aberdeen Proving Ground

Aberdeen Proving Ground Edgewood Area (APG-EA) is an active U.S. Army post located in Edgewood, MD, USA (39.39°N, 76.29°W), and is composed of approximately 13,000 acres. The post operates a regularly used outdoor recreation trap and skeet range (E4737). The facility is in southern Harford County and southeastern Baltimore County, Maryland, on the western shore of the Chesapeake Bay, and is bordered by the bay to the east and south. The area is characterized by a few broad hills with surface elevations up to 35 feet, to low lying areas less than 10 feet. Much of APG-EA is covered with extensive woodlands and wetlands that provide habitat for many animals, including white tail deer, foxes, and wild turkeys. The area is primarily mixed hardwood forest dominated by oaks, American beech and Virginia pine, and an understory of American holly and sassafras. The habitat is also partly composed of tulip trees, maple, sweet gum, and mowed or developed fields.

5.2.2 SAMPLING METHODS

Sample Collection

Small mammals were collected with Sherman live traps from Range 17 in April and E4737 in August of 2012. One-hundred traps were placed in a grid pattern at Range 17, and 50 traps were set at site E4737 that were separated about 10 feet apart as the terrain allowed. GPS was used to uniquely identify and record each trap location. Trapping was conducted for one week at each site. An estimated ten adults/gender/species was the collection target for each location: this target has been determined to be adequate using SEEM from an earlier songbird study (Johnson *et al.*, 2007). Traps were baited with rolled oats, opened each evening at dusk, and checked the following morning. Empty traps were closed each morning to prevent animals from being inadvertently contained in the metal live trap during the heat of the day. Cotton squares were placed in each set trap to minimize captured animals' heat loss while in the trap overnight. Soil and vegetation samples were co-collected at each trap location where an animal was caught for later lead analysis.

Captured animals were identified for gender, age, reproductive condition (when possible), and measured for body weight and length. Blood samples were collected via the facial vein, saphenous vein, or tail (*Peromyscus* only). Blood flow and collection success was increased by warming the site using gentle friction or disposable hand-warmers. Veins were punctured with a lancet and blood was collected in microhematocrit capillary tubes and immediately transferred to EDTA vials. Blood flow was stopped with direct pressure or a styptic pencil cauterizing agent. A maximum of two males and two females per species at each trapping site were euthanized for stomach content analysis. Euthanasia was accomplished by placing the animals in a small plastic bag containing cotton soaked isoflurane; euthanasia was confirmed by cervical dislocation. Animals not euthanized for stomach content analysis were taken to the original site of capture and released immediately after processing.

This study was conducted in compliance with Good Laboratory Practice (GLP) regulations found in the Toxic Substances Control Act (TSCA): 40 CFR (Code of Federal Regulations) 792, plus amendments.

Blood Lead Analysis

Blood was shipped overnight on ice to the Wadsworth Center, New York State Department of Health for determination of lead concentrations. Samples were analyzed using Graphite Furnace Atomic Absorption Spectrometry (GFAAS, Parsons and Slavin 1993); certified samples were used to ensure quality control. Samples with small fibrin clots were digested with concentrated nitric acid following mass determination and analyzed aFt.er correcting results to account for the acid dilution.

Vegetation Lead Analysis

Vegetation samples were weighed into separate beakers and dried at approximately 50°C in a laboratory oven for approximately 36 hours. Samples were then cut into pieces using nonmetallic scissors and wet digested at approximately 90°C using a mixture of nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). The solutions were then filtered using ashless filter paper and diluted to final volume (50 mL) using 2% v/v (HNO_3/H_2O). The samples were analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) on a PerkinElmer Elan 6000 ICP-MS. Two laboratory control samples (locally acquired grass samples spiked with a known amount of lead at two different concentrations), two method blanks (reagents/acids), and locally acquired grass samples were analyzed witht the study samples. Both LCS samples were within current acceptable limites. Both blanks were determined to have a value above the Limit of Quantitation however, due to the source of the material used for the blank (locally acquired grass sample), the impact of elevated concentrations on the sample concentration is unknown.

Stomach Content Analysis

Stomach content samples were preserved in the filed with formalin. The bulk formalin was removed from the samples using disposable plastic pipettes; samples were then centrifuged at approximately 10 x G for 10 minutes to aid in removing additional formalin. Sampels were weighed out into separate glass vials and dried at approximately 50° C and -25 in Hg pressure (vacuum) in a laboratory vacuum oven until a constant weight was achieved (approximately 4 days). Samples were then combusted using ambient air, at approximately 500°C in a muffle furnace for approximately 24 hours and allowed to cool to ambient temperature and reweighed. Ashes were then transferred to Teflon microwave digestion tubes and microwave digested in a solution containing a mixture of nitric (HNO_3), hydrochloric (HCl), and hydrofluoric (HF) acids. The digested solutions were then transferred into Teflon beakers and heated on a hot plate to reduce volume. Samples were then diluted to final volume (50 mL) using 20% v/v HNO_3/H_2O. Samples were analyzed for lead concentration by ICP-MS on a PerkinElmerElan 6000 ICP-MS. A method blank and two laboratory control samples were analyzed with the samples. Both laboratory control samples were within current acceptable limits. The method blank was determined to have a value above the Limit of Quantitation. The elevated blank concentration was less than ten times the sample concentration and should not impact reported sample concentrations.

Data Analysis

Analysis was similar to that used with songbirds caught at small arms ranges (Johnson *et al.*, 2007). Blood lead levels from mammals in this study were used to develop a hazard quotient using a tissue specific toxicity reference value (i.e., a blood lead toxicity reference value) for mammals. Species-specific hazard quotients will be compared with the SEEM modeled hazard quotient output (Monte Carlo generated population of hazard quotients). Comparisons will be made of the upper 10% hazard quotients with those from each species and compare those with a conventional generated hazard quotient level. Success will be determined if these values are less than (not valued) or greater than (valued) an order of magnitude (10x). Preliminary reference area data for blood lead and information from an avian study used to validate SEEM were evaluated to assist in the determination of sample size. Daily records were kept on survival and clinical signs of collected animals. Procedures for preparation of any euthanasia solution, drug administration, animal bleeds, observation logs, morbidity/mortality logs, etc. were stored. These records will be made available to oversight organizations such as the U.S. EPA, AAALAC, and the IACUC. The protocol, protocol amendments, raw data, data analysis, tabular calculations, and graphic analysis of the data will be saved with the study records. Additionally, memoranda to the study file, study logs, final reports, and final report amendments will be archived at PTOX.

5.2.3 SAMPLING RESULTS

Blood lead concentrations from small mammals collected at Fort Meade and Aberdeen Proving Ground are shown below (Tables 5.1 and 5.2). Capture locations correspond to trap sites illustrated in Figures 5-1 and 5-2. Blood lead levels from small tailed shrews (*Blarina brevicauda*) are much higher than those from rodents due to the insectivores being from a higher trophic level.

Figure 5-1. Ft. Meade Range 7 Trap Locations (show as blue colored disk areas on the map).

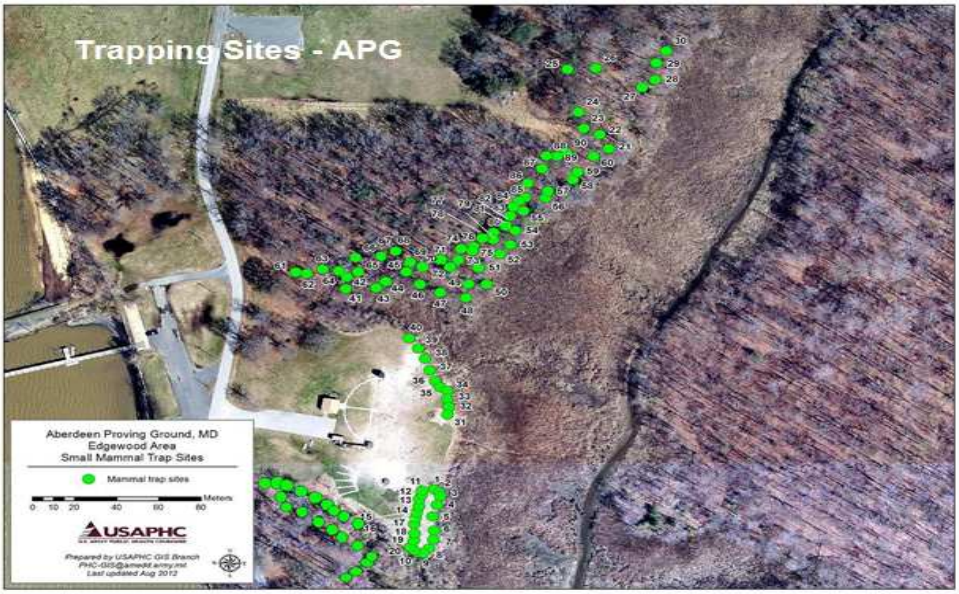

Figure 5-2. Aberdeen Proving Ground – Edgewood Area trapping sites (shown as green colored disk areas on the map).

Table 5-1. Blood lead levels from small mammals caught at Ft. Meade.

Species	Capture Location	Age	Gender	Blood Pb µg/dL
Pe.le.	53	adult	male	1
Cl. ga.	80	adult	male	18
Pe.le.	15	juvenile	female	22
Pe.le.	28	adult	male	2
Pe.le.	100	adult	male	5
Cl. ga.	80	adult	female	20
Pe.le.	82	adult	male	<DL
Pe.le.	62	juvenile	male	8
Pe.le.	59	juvenile	male	22
Pe.le.	43	adult	male	9*
Pe.le.	21	adult	male	<DL
Pe.le.	2	adult	male	5
Pe.le.	28	adult	male	8
Pe.le.	90	adult	female	1
Pe.le.	11	adult	female	2
Pe.le.	18	adult	female	15*
Pe.le.	53	juvenile	female	4

Pe.le. = *Peromyscus eucopus*
Cl. ga. = *Clethrionomys gapperi*

Table 5-2. Blood lead levels from mammals caught at Aberdeen Proving Ground.

Species	Capture Location	Age	Gender	Blood Pb µg/dL
Pe.le.	32	juvenile	male	6
Pe.le.	41	adult	male	1
Pe.le.	27	adult	male	5
Pe.le.	60	adult	male	2
Bl. br.	32	adult	male	38
Pe.le.	24	adult	female	1
Pe.le.	53	adult	male	4
Bl. br.	89	adult	male	125
Pe.le.	75	adult	male	14
Pe.le.	24	adult	male	4

Pe.le. = *Peromyscus leucopus*
Bl. br. = *Blarina brevicauda*

Table 5-3. Stomach content lead concentrations from small mammals collected from Ft. Meade and Aberdeen Proving Ground (APG).

Site	Species	Capture Location	Age	Gender	Pb (µg/kg)
Ft. Meade	Cl. ga.	80	adult	male	0.006
Ft. Meade	Cl. ga.	80	adult	female	0.003
Ft. Meade	Pe.le.	53	adult	male	0.001
Ft. Meade	Pe.le.	15	juvenile	female	0.003
Ft. Meade	Pe.le.	28	adult	male	0.003
Ft. Meade	Pe.le.	90	adult	female	0.002
APG	Bl. br.	32	adult	male	0.005
APG	Bl. br.	89	adult	male	0.008
APG	Pe.le.	32	juvenile	male	0.008
APG	Pe.le.	24	adult	female	0.001

Cl. ga. = *Clethrionomys gapperi*
Pe. le. = *Peromyscus leucopus*
Bl. br. = *Blarina brevicauda*

Table 5-4. Lead analysis results from vegetation collected at capture locations of small mammals collected from Ft. Meade and Aberdeen Proving Ground (APG).

Site	Sample ID	Capture Location	Pb (µg/kg)
Ft. Meade	1	53	0.00425125
Ft. Meade	2	80	0.00745567
Ft. Meade	8	62	0.00313611
Ft. Meade	13	28	0.01139030
Ft. Meade	15	11	0.02201117
APG	1	32	0.00655942
APG	2	41	0.00422335
APG	3	27	0.00204131
APG	4	60	0.01725492
APG	5	32	0.02497396
APG	6	24	0.03320187
APG	7	53	0.03051924
APG	8	89	0.01171209
APG	9	75	0.02978203
APG	10	28	0.00182963

Stomach and vegetation lead concentration results are shown above (Tables 5.3 and 5.4). A subsample of mammals from each site (goal of two of each gender per species per study site) were euthanized and stomach contents were analyzed for lead concentrations. Contents from shrews had higher concentrations of lead than those from rodents due to greater biomagnification of lead in the shrew's prey items than the vegetation that comprised the rodents' diets. Vegetation concentrations come from plant material that was collected at each trap site where a small mammal was captured. Capture locations correspond to trap sites illustrated in Figures 5-1 and 5-2.

5.3 SEEM MODELING

In addition to the soil chemistry and the habitat suitability data summarized above, a number of inputs are required to run the SEEM model for each species. These inputs include: time scale, chemicals, receptors, food items and ingestion rates, soil ingestion rates, bioaccumulation factors, foraging radius, and toxicity reference values. The selected values for each of these inputs for each study site are presented in the sections that follow.

5.3.1 THE ROAD AND GUN CLUB SKEET RANGE AT ABERDEEN PROVING GROUND, MARYLAND

A demonstration model was assembled for three small mammalian receptors that represent herbivores, insectivores, or omnivores. Each mammal was assumed to ingest soil contaminated

with lead through either incidental soil ingestion with the diet, or by direct contact with the soil while foraging. The model was developed for Aberdeen Proving Ground Gun Club, located in Aberdeen, Maryland. The information presented below serves as the input data for the APG SEEM Version 4.2 model, and is intended to accompany the model that was developed.

Time Scale

The default seasons time scale was selected for this model. SEEM therefore automatically entered 92 days for winter, and 91 days for spring, summer, and autumn. No changes were made to the number of days or seasons.

Chemicals

Lead was the only chemical selected for analysis by SEEM for this model. The CAS# was entered as 7439-92-1.

Receptors

The white-footed mouse (*Peromyscus leucopus*), the short-tailed shrew (*Blarina brevicauda*), and the southern red-backed vole (*Clethrionomys gapperi*) were the three mammalian receptors utilized in these models.

The white-footed mouse and short-tailed shrew were both noted during site visits. The southern red-backed vole was assumed to be present because it had previously been noted at the Fort Meade site.

Food Items and Bioaccumulation Factors

The food items included plants, insects, and earthworms. Bioaccumulation factors (BAF) for lead in soil to plants and earthworms as dietary items were selected from USACHPPM (2004). The median BAF for soil to earthworms was selected from Table 4.2 and is equal to 3.342. The median BAF for soil to plants was also selected from Table 4.2 and is equal to 0.0388. The BAF for soil to insects was equal to 23.8301 taken from the U.S. Army TWEM database, as reported in a table entitled "Estimation of Earthworm Body Burdens, BAAP Ecological Risk Assessment, Baraboo, Wisconsin." [Note: the actual U.S. Army TWEM database was not accessible for verification at the time of writing.]

Foraging Radius

Foraging radius was calculated when representing the home range as a circle and determining the radius. The largest home ranges reported in U.S. EPA (1993) were selected to be conservative. The white-footed mouse home range was 0.059 ha, based on a mean of male and female mice in a mixed deciduous forest in Virginia (Wolff 1985, and as cited in Sample and Suter GW, 1994). The minimum estimates of the red-backed vole home range vary from 0.5 to 0.07 ha according to a review by McManus (1974); a 0.07 ha home ranged was selected. The shrew home range was based on an average (0.39 ha) that was reported for the short-tailed shrew in Michigan, Manitoba

and New York (Blair 1940, Buckner 1966, Platt 1976). The home range, reported in hectares, was first converted to units of meters-squared, and then divided by pi. The square root of the radius was calculated to provide input as the foraging radius.

Example calculation: 0.059 ha = [590 m^2 / 3.14] = [187.9 $m^2]^{1/2}$ = 13.7

The foraging radius for each species is summarized in Table 5.5.

Table 5-5. Foraging radius calculated for each receptor species (APG).

	Area (hectares)	**Area (m^2)**	**Radius (m^2)**	**Foraging Radius (m)**
Mouse	0.059	590	188	13.7
Shrew	0.39	3900	1242	35.2
Vole	0.07	700	223	14.9

Diets

The percentages of food items for each receptor were based on best professional judgment along with information provided in the U.S. EPA, Exposure Factors Handbook (1993). The vole was assumed to be an obligate herbivore, consuming 100% plants. In contrast, the shrew was assumed to be an insectivore, consuming 70% soil insects and 30% earthworms in the diet. The mouse was thought to consume approximately 50% each insect and plant material.

Food and Soil Ingestion Rates

Food ingestion rates were based on allometric equations for food consumption presented in Nagy (1999). Soil ingestion rates used estimates presented by either Beyer *et al.* (1994) or Sample and Suter (2004).

The white-footed mouse (22 g) food consumption rate was based on Green and Millar (1987, and as cited in Sample, 1994) and the allometric equation for omnivorous mammals (Nagy et al., 1999). The food ingestion rate (dry weight or DW) for the white-footed mouse is 3.5 g (DW)/day, or 0.16 kg (DW)/kg (body weight or BW)/day. The soil ingestion rate was approximately 2% of the diet using the rate reported for the white-footed mouse (Beyer *et al.*, 1994).

The short-tailed shrew (15 g) food consumption rate for females and males, in New Hampshire, was reported by Schlessinger and Potter (1974) in U.S. EPA. The allometric equation for food

consumption in herbivorous mammals (Nagy, 1999) calculated the food consumption rate at 2.32 g DW/d or 0.15 kg DW/kg BW/day. Soil ingestion rate was estimated at 13% of the diet, based on Talmage and Walton (1993, and as cited in Sample and Suter, 1994).

The red-backed vole food consumption rate was based on the mean minimum body weight of 24 g for laboratory voles, according to McManus (1974). Using the allometric equation for food consumption for herbivorous mammals (Nagy, 1999), the calculated food consumption rate is 6.19 g DW/d, or 0.25 kg DW/kg BW/day. The soil ingestion rate was estimated at 2.4% of the diet (dry weight), according to Beyer *et al.*, (1994).

Toxicity Reference Values

The no-observed adverse effects levels and lowest-observed adverse effects levels toxicity reference values for mammals were selected from the ecological soil screening level document (U.S. EPA, 2005). The TRV is equal to the highest bounded NOAEL below the lowest bounded LOAEL for reproduction, growth, or survival, and is equal to 4.7 mg lead/kg bw/day. The LOAEL was actually the geometric mean of the NOAEL values for reproduction and growth because it was higher than the lowest bounded LOAEL. The LOAEL was therefore considered to be 40.7 mg lead/kg bw/day.

5.3.2 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94, FT. MEADE) AT PATUXENT RESEARCH REFUGE, LAUREL, MARYLAND.

A demonstration model was assembled for three mammalian receptors that represent herbivores, insectivores, or omnivores. Each mammal was assumed to ingest a portion of soil contaminated with lead either through diet or direct contact with soil during foraging. The information presented below serves as the input data for the SEEM Version 4.2 model, and is intended to accompany the model that was developed.

Time Scale

The default seasons time scale was selected for this model. SEEM therefore automatically entered 92 days for winter, and 91 days for spring, summer, and autumn. No changes were made to the number of days or seasons.

Chemicals

Lead was the only chemical selected for analysis by SEEM for this model. The CAS# was entered as 7439-92-1.

Receptors

Three mammalian receptors were utilized in these models including:
short-tailed shrew (*Blarina brevicauda*), red-backed vole (*Clethrionomys gapperi*), and White-footed mouse (*Peromyscus leucopus*).

Food Items and Bioaccumulation Factors

The food items included plants, insects, and earthworms. Bioaccumulation factors for lead in soil to plants and earthworms as dietary items were selected from USACHPPM (2004). The median BAF for soil to earthworms was selected from Table 4.2 and is equal to 3.342. The median BAF for soil to plants was also selected from Table 4.2 and is equal to 0.0388.

The BAF for soil to insects was equal to 23.8301 taken from the U.S. Army TWEM database, as reported in a table entitled "Estimation of Earthworm Body Burdens, BAAP Ecological Risk Assessment, Baraboo, Wisconsin." [Note: the actual U.S. Army TWEM database was not accessible for verification at the time of writing].

Foraging Radius

Foraging radius was calculated when representing the home range as a circle and determining the radius. The largest home ranges reported in U.S. EPA (1993) were selected to be conservative. The white-footed mouse home range was 0.059 ha, based on a mean of male and female mice in a mixed deciduous forest in Virginia (Wolff 1985, as reported in Sample 1994). The minimum estimates of the red-backed vole home range size vary from 0.5 to 0.07 ha according to a review by McManus (1974); a 0.07 ha home ranged was selected.

The shrew home range was based on an average home range (0.39 ha) reported for short-tailed shrew in Michigan, Manitoba and New York (Blair 1940, Buckner 1966, Platt 1976). The home range, reported in hectares, was first converted to units of meters-squared, and then divided by pi. The square root of the radius was calculated to provide input as the foraging radius.

Example calculation: $0.059 \text{ ha} = [590 \text{ m}^2 / 3.14] = [187.9 \text{ m}^2]^{1/2} = 13.7$

The foraging radius for each species is summarized in Table 5-6.

Table 5-6. Foraging radius calculated for each receptor species (Ft. Meade).

	Area (hectares)	**Area (m^2)**	**Radius (m^2)**	**Foraging Radius (m)**
Mouse	0.059	590	188	13.7
Shrew	0.39	3900	1242	35.2
Vole	0.07	700	223	14.9

Diets

The percentages of food items for each receptor were based on best professional judgment along with information provided in the U.S. EPA Exposure Factors Handbook (1993). The vole was assumed to be an obligate herbivore, consuming 100% plants. In contrast, the shrew was

assumed to be an insectivore, consuming 70% soil insects and 30% earthworms in the diet. The mouse was thought to consume approximately 50% each insect and plant material.

Food and Soil Ingestion Rates

Food ingestion rates were based on allometric equations for food consumption presented in Nagy (1999). Soil ingestion rates used estimates presented by either Beyer *et al.*, (1994) or Sample and Suter (2004).

The white-footed mouse (22 g) food consumption rate was based on Green and Millar 1987 (reported in Sample 1994) and the allometric equation for omnivorous mammals (Nagy, 1999). The food ingestion rate (dry weight) for the white-footed mouse is 3.5 g (DW)/day, or 0.16 kg (DW)/kg (BW)/day. The soil ingestion rate was estimated at approximately 2% of the diet using the rate reported for the white-footed mouse (Beyer *et al.*, 1994).

The food consumption rate for female and male short-tailed shrews (15 g) in New Hampshire was reported by Schlessinger and Potter (1974) in U.S. EPA. The allometric equation for food consumption in herbivorous mammals (Nagy, 1999) calculated the food consumption rate at 2.32 g DW/d or 0.15 kg DW/kg BW/day. Soil ingestion rate was estimated at 13% of the diet, based on Talmage and Walton (1993; as cited in Sample and Suter, 1994).

The red-backed vole food consumption rate was based on the mean minimum body weight of 24 g for laboratory voles, according to McManus (1974). Using the allometric equation for food consumption for herbivorous mammals (Nagy, 1999), the calculated food consumption rate was 6.19 g DW/d, or 0.25 kg DW/kg BW/d. The soil ingestion rate was estimated at 2.4% of the diet (dry weight), according to Beyer *et al.*, (1994).

6.0 PERFORMANCE ASSESSMENT

A detailed review of the performance of the study in meeting the stated objectives is provided in Section 3.0. Below we provide the results of the model verification study.

6.1 PERFORMANCE OBJECTIVE: FURTHER VERIFY THE SPATIALLY-EXPLICIT EXPOSURE MODEL (SEEM) RESULTS FOR MAMMALIAN AND AVIAN WILDLIFE

The results of the modeling effort did not compare well with the directly measured exposure assessment for small mammals. The model results are summarized below

6.1.1 THE ROD AND GUN CLUB SKEET RANGE AT ABERDEEN PROVING GROUND, MARYLAND

The SEEM results for APG are provided in Figures 6-1 and 6-2. The figures that follow are the raw graphical output of the SEEM model. They capture the average daily hazard quotient (which equals the average daily dose divided by a toxicity reference value) versus the percent of the population with that hazard quotient.

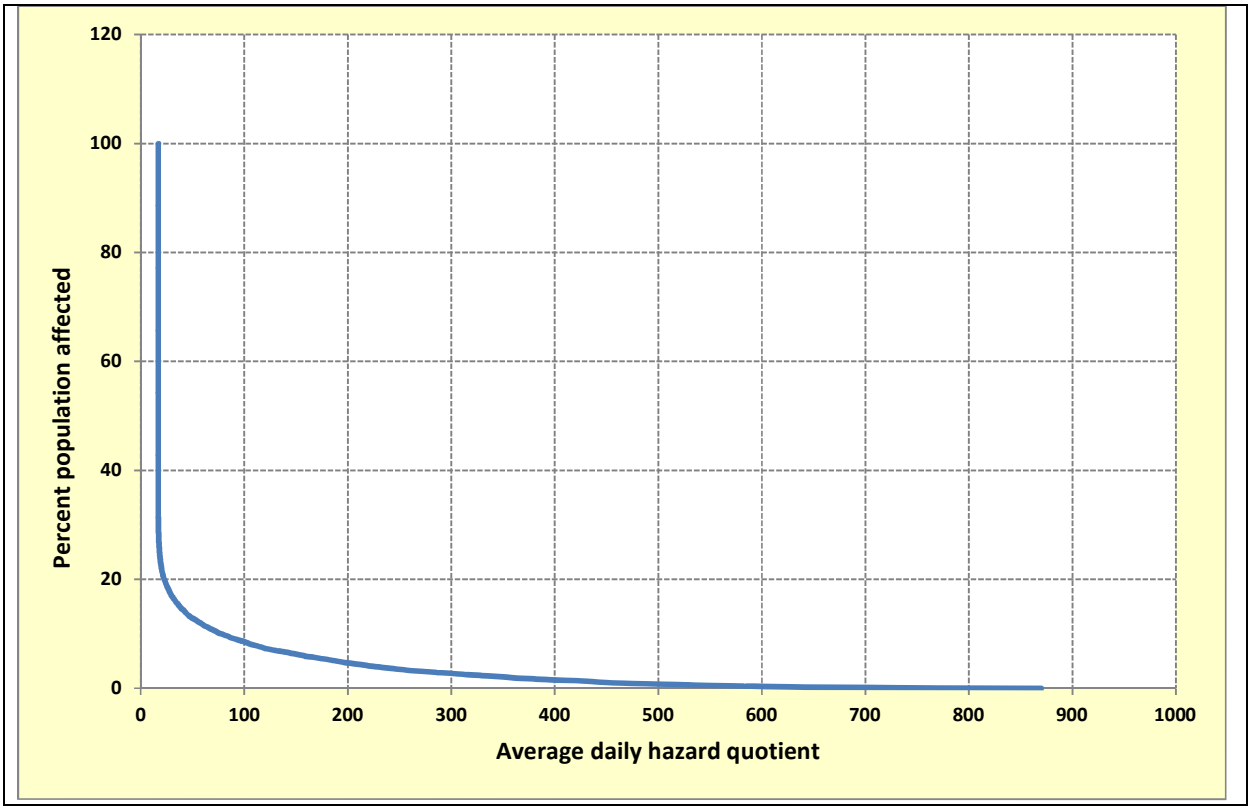

Figure 6-1. SEEM summary figure for *Blarina brevicauda* at APG with average exposure and chronic high TRV (40.7 mg/kg).

For example, in Figure 6-1 (above), 10% of the population an average daily hazard quotient of 100 or greater. In general, a hazard quotient exceeding 1 requires additional review because the exposure exceeds the effect concentration. Figure 6-6 (below) provides an overall summary of the results of SEEM, the deterministic calculations and blood lead evaluation. For SEEM results, we selected the average daily hazard quotient for the upper 10% of the modeled population.

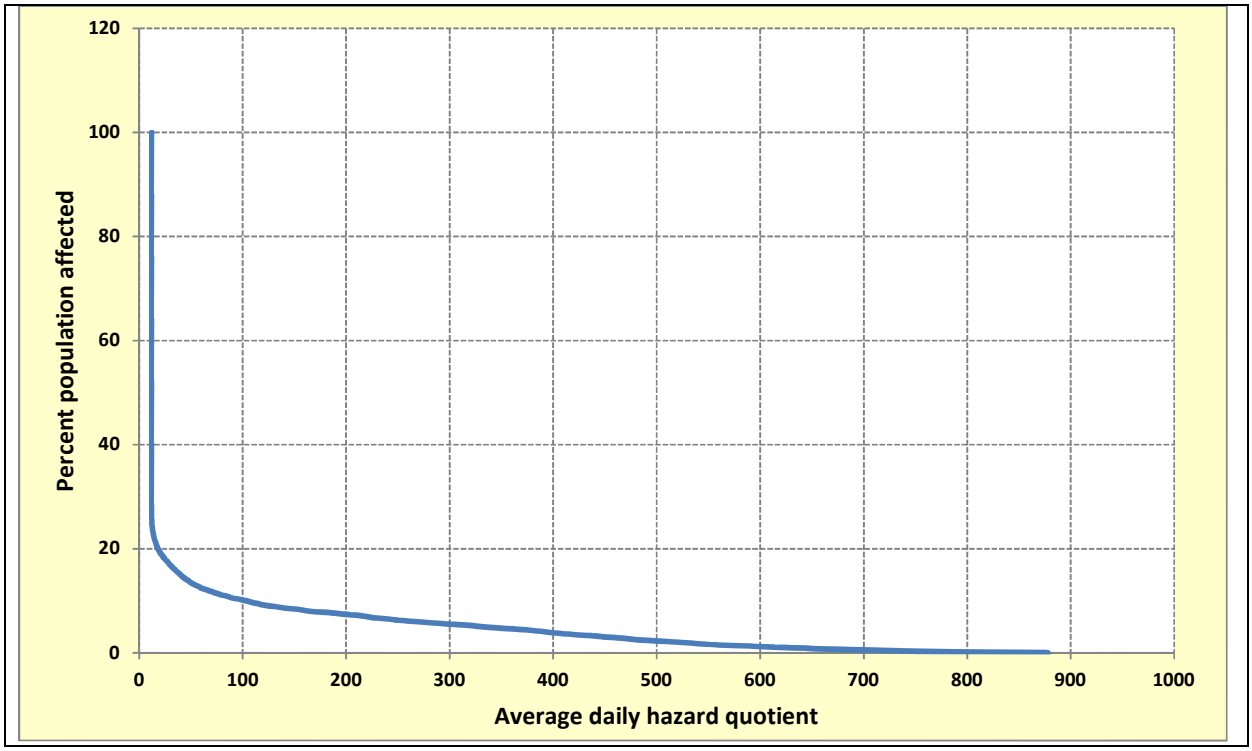

Figure 6-2. SEEM summary figure for *Peromyscus leucopus* at APG with average exposure and chronic high TRV (40.7 mg/kg).

6.1.2 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94, FT. MEADE) AT PATUXENT RESEARCH REFUGE IN LAUREL, MARYLAND

The SEEM results are provided in Figure 6-3 and Figure 6-4 below.

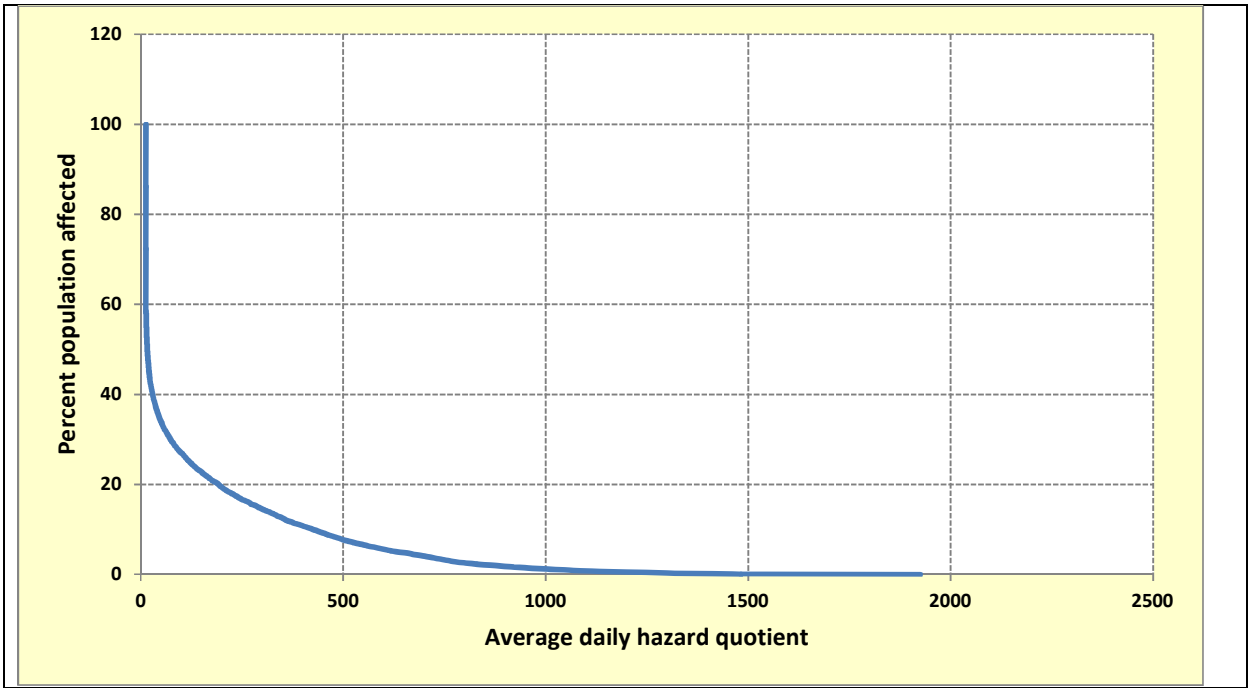

Figure 6-3. SEEM summary figure for *Peromyscus leucopus* at Ft. Meade with average exposure and chronic high TRV (40.7 mg/kg).

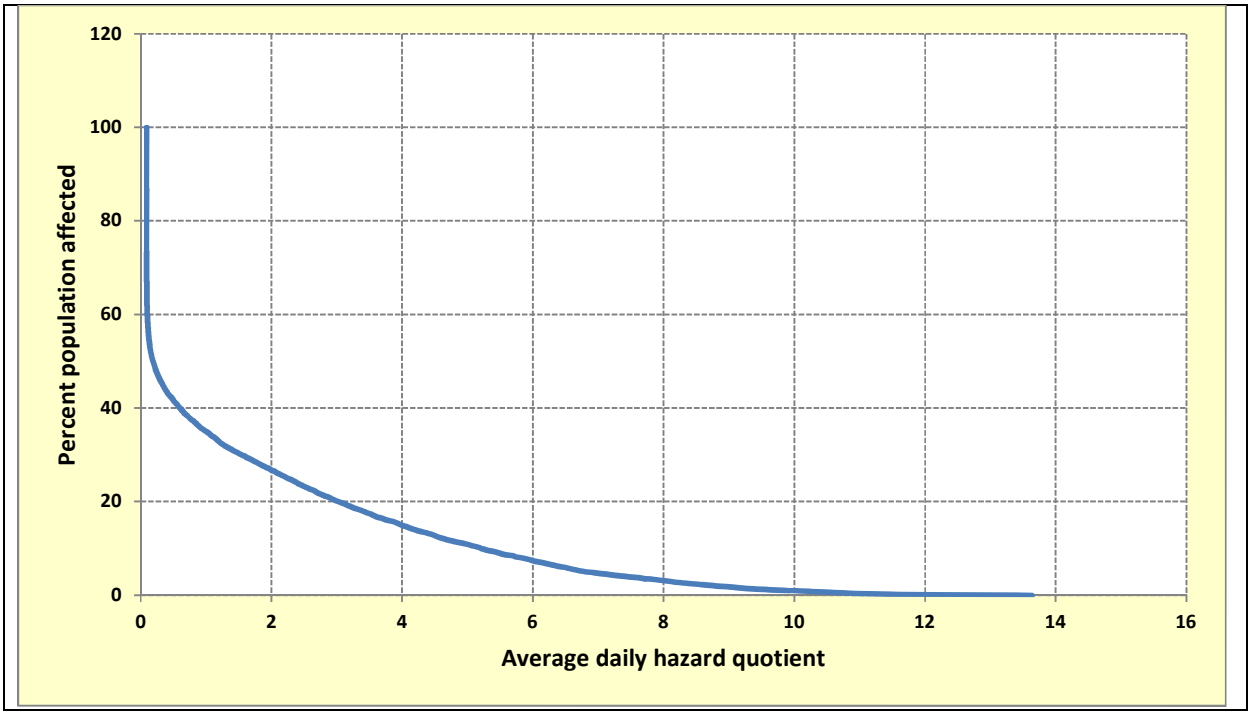

Figure 6-4. SEEM summary figure for *Clethrionomys gapperi* at Ft. Meade with average exposure and chronic high TRV (40.7 mg/kg).

6.1.3 BLOOD LEAD ASSESSMENT RESULTS

The results of the blood lead evaluation for both sites are summarized in Figure 6-5. The green line is a blood lead screening value of 18 ug/dL (Buekers *et al.*, 2009).

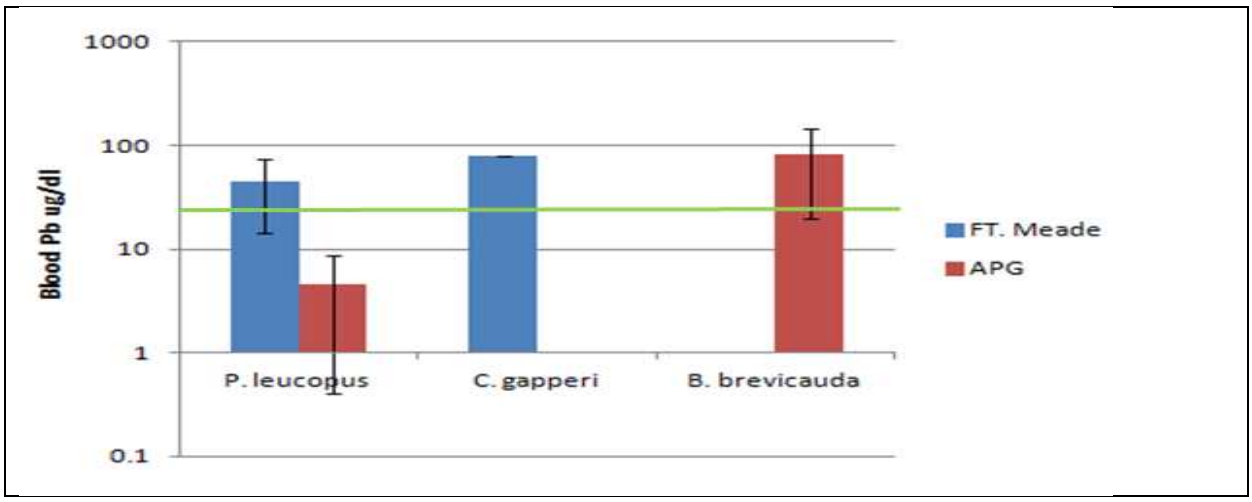

Figure 6-5. Demonstration site small mammal blood lead concentrations compared to the critical blood lead level of 18 ug/dl (Buekers *et al.*, 2009).

6.1.4 COMPARISON

Unlike the avian verification (Johnson *et al.*, 2007), small mammal model outputs were more similar with the deterministic results, and not with the directly measured blood lead concentrations (Figure 6-6).

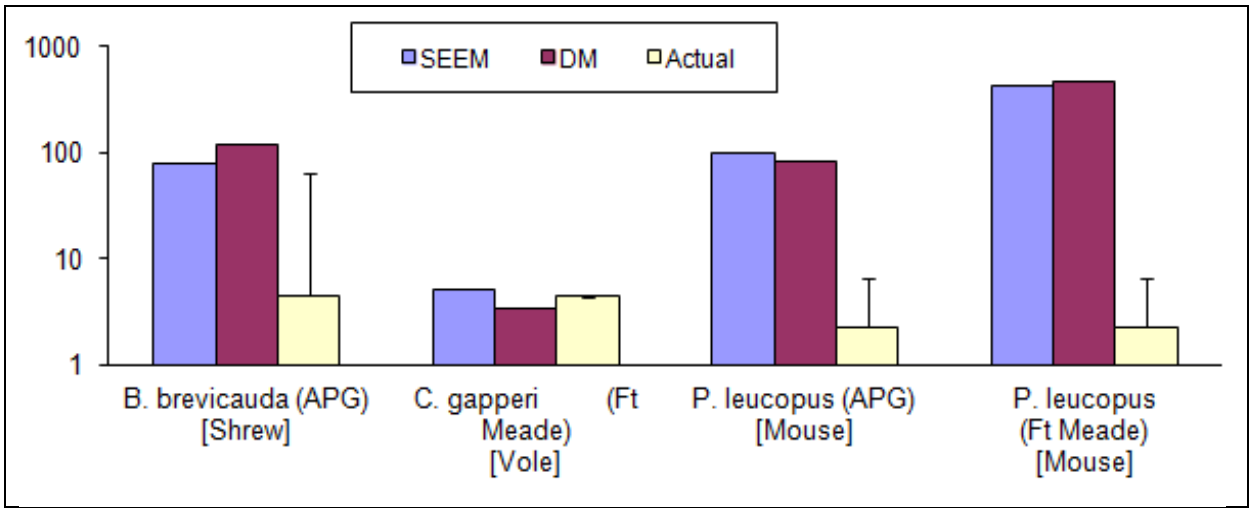

Figure 6-6. Comparison of estimated risks using the SEEM model and those calculated using the blood level. Comparisons based on hazard quotients (x-axis).

The deterministic calculation was based on the single soil lead concentration of the 95% Confidence Level of the mean value or highest sample result, whichever was lower and was used to estimate exposure. The same toxicity value used in the random walk model in the SEEM iteration was also used."

Although the results do not verify model applicability to small mammals, they reinforce the need to understand the assumptions and the landscape over which the model is run. In this case, the combination of small foraging areas and large tracts of relatively homogeneous habitat results in minimal differences between the site-wide deterministic calculation and the SEEM modeled results. This is not a failure of the model, but rather demonstrates that for these species there needs to be a much finer resolution of habitat and chemical assessment. The source of the issue is illustrated in Figures 6-7 and 6-8.

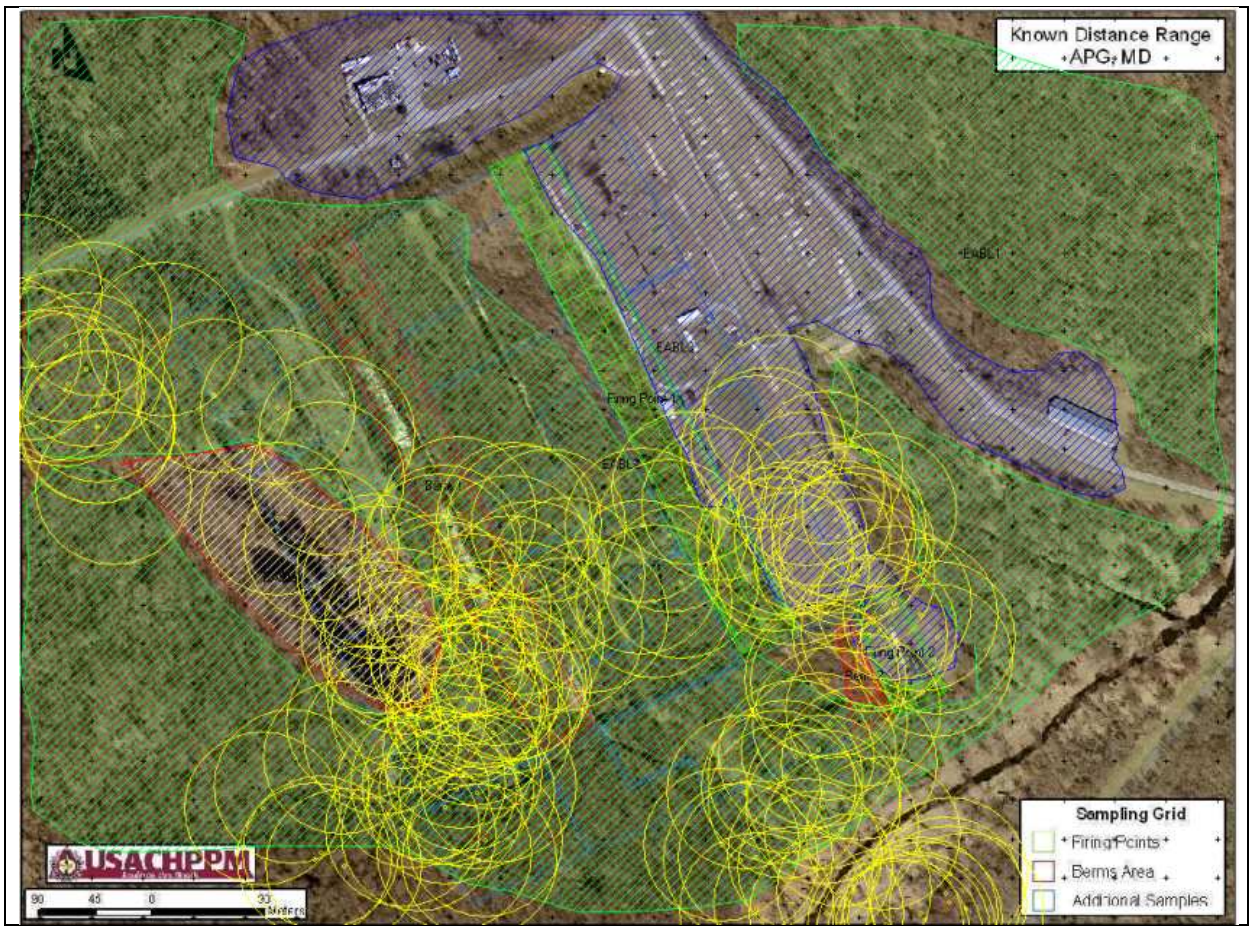

Figure 6-7. Foraging range for a single model run (365 days) for an individual bird.

The movement of one mammal compared to that of a single bird over the modeling period illustrates the disconnect for small mammals. The bird exposure covers multiple habitats across the site (Figure 6-7), while small mammals may rarely move to a new habitat type because their limited foraging radius (Figure 6-8).

Microhabitat data would improve the value of the model. Also, application to large mammals may confirm this explanation for model divergence with small mammal species.

Figure 6-8. Foraging range for a single model run (365 days) for an individual small mammal. Note that the small mammal foraging range is captured by the small yellow polygon in the middle of the picture highlighted by the red colored for identification.

6.2 PERFORMANCE OBJECTIVE: IMPROVE AND REFINE SEEM AS A CONSEQUENCE OF THIS EFFORT

See full discussion in Section 3.2.

6.3 PERFORMANCE OBJECTIVE: EASE OF USE

See Full discussion in Section 3.3.

6.4 PERFORMANCE OBJECTIVE: DEVELOP A PUBLICATION TO SHARE OUR FINDINGS, MODEL UPDATES AND CONCLUSIONS REGARDING THE VALUE OF SPATIAL MODELS

See full discussion in Section 3.4.

7.0 COST ASSESSMENT

In this case, the cost assessment focuses on the first performance objective only – "Further Verify the Spatially-explicit Exposure Model (SEEM) Results For Mammalian and Avian Wildlife."

There are two primary components to the cost estimate of the model verification summarized in the previous sections. We separate them for the sake of clarity. Ultimately, the goal is to identify sites and stages of an assessment during which SEEM might be run to understand wildlife exposure independent of directly measured exposures.

7.1 COST MODEL

7.1.1 SEEM MODEL RUN

A simple cost model for the technology is provided in Table 7-1. Specific task assumptions are provided in the table, but the general assumptions include:

- Estimates are for a single location and 3 receptors
- Inputs were collected from literature sources, electronic databases (maps and some chemistry data) and through hand-entered data tables
- The estimated costs do not include field sampling efforts

Table 7-1. Cost model for setup and running a SEEM for one demonstration site.

Cost Element	Data Tracked During the Demonstration	Costs	
Site Review	• Document review – locate chemistry data and receptors • Map selection • Select receptors	Project Scientist Project Manager	12 hrs 4 hrs

Cost Element	Data Tracked During the Demonstration	Costs	
Assemble Model Inputs – Chemical Data	• Assemble chemistry data – spreadsheet • Quality review of data • Fill data gaps and combine data sets as needed • Review data distributions and select (if needed) geospatial averaging approach • Based on geospatial averaging create polygons of chemical concentrations	Project Scientist GIS/Statistician (interpolation) Project Manager	16 hrs 10 hrs 4 hrs
Assemble Model Inputs – Species Exposure Values	• Review key literature/study sources for species-specific inputs • Preference for field collected or site-specific data	Project Scientist Project Manager	14 hrs 4 hrs
Assemble Model Inputs – Habitat Suitability	• Locate habitat/land cover maps • If pre-identified land cover maps are not available use remote sensing to delineate habitat types	Project Scientist Project Manager	14 hrs 4 hrs
Insert Model Inputs using Guided Input Steps in SEEM	• Inputs assembled outside of SEEM, then hand entered • Polygons for chemistry and habitat are combined and imported on the image file then traced within SEEM • Habitat suitability indices are assigned to habitat types – in this case based on professional judgment	Project Scientist	10 hrs
Run SEEM	• Model runs are on the order of 2-3 minutes • Report generation can take 5 minutes • Iteration with varying inputs is useful for sensitivity analysis	Project Scientist	5 hrs
TOTAL		**Total Cost: $7,000 - $9,000**	

7.2 COST DRIVERS

Anticipated cost drivers should be carefully considered when selecting the technology for future implementation. Highlight any site-specific characteristic that will significantly impact cost. Provide examples of how costs will impact technology implementation.

The SEEM model components that most directly influence the final cost are the inputs. Populating and running the model are not time consuming or require a large investment of money. The inputs are divided into three general categories. Each is briefly described below and the range of effort is introduced.

7.2.1 CHEMICAL CONCENTRATIONS

When considering the cost unique to SEEM application it is important to consider the availability of existing chemical data. In some cases SEEM application will be added to a site assessment after initial analyses have been completed. In this case there may be a comprehensive chemical data set available and no additional data will be needed. The cost under this example might be the cost to extract the data from an existing database. On the high end of chemical analysis costs is the case where there are no existing data or the existing data are not reflective of current conditions.

In this case, a full field sampling plan and laboratory assessment will have to be completed with an expense in the thousands of dollars depending on the size of the area and required samples. The most common scenario, however, falls between the extremes with some existing data, but with gaps. For SEEM to be effective the chemical concentrations must cover not only the areas where the release or spill occurred, but also areas where wildlife might forage that may not be impacted by the release. In many cases the data collected to support SEEM modeling are used for other site assessment activities. At the two demonstration sites described previously a combination of historic datasets and recently collected XRF data were used in our models.

7.2.2 HABITAT SUITABILITIES

Habitat suitability is one of the core components of the model. The level of effort and, therefore, cost required to characterize habitat suitability varies from desk-based estimation using widely available aerial and satellite photos and land-use typing by government agencies to a detailed collection of metrics assembled to quantitatively determine the quality of habitat. The most appropriate habitat characterization will depend on the specific project needs and budget. Costs will be highly variable.

On the low end of the range, many aerial photos are available at no cost online so the only expense is for the scientist to review the habitats and assign weights. This can be a step that takes no longer than a few hours. In contrast, attempting to populate a species-specific habitat suitability index with field-collected data can require days or weeks of in-field time spent measuring key metrics. The more common, low-to-moderate cost approach is to begin with

available electronic photos and maps and an initial habitat suitability ranking, followed by an on-the-ground reconnaissance to confirm the ranking assumptions. At the demonstration sites in this study habitat cover maps were used to rank quality with respect to the type of habitat available and receptor preferences. Some ground truthing was possible during soil collections.

7.2.3 BIOACCUMULATION AND INGESTION RATES

SEEM is not a bioaccumulation model, but having quality inputs when possible will increase the value of the outputs. In general, bioaccumulation, ingestion rates, and diet composition (including percent soil in diet) are factors that are measurable, but for SEEM this data is usually acquired from literature studies. Therefore, the cost of these inputs is considered to be low. However, if the opportunity presents itself during site work any directly measured tissue data, ingestion rates, or diet composition data can improve the model.

7.3 COST ANALYSIS

The analysis of the cost of running SEEM on a project begins with a review of the goals of the project. SEEM is a valuable tool for visualizing patterns of exposure on the site, exploring different remedial scenarios with respect to habitat, receptor and chemical interactions, and understanding risk with respect to a group of individuals or a modeled population. Costs will vary depending on who is tasked with assembling the inputs and running the model. The model has been designed with stepwise guidance both within the model and through a companion user manual to facilitate efficient use of the model.

Although not a requirement, in our experience SEEM is generally used at sites that have some level of completed assessment including chemical screening of the media. There may be gaps that need to be filled, but in most cases SEEM can be run with a base level of chemical data and access to habitat maps (many available free on state websites).

Users will need to balance model specificity with level of investment available. The model is most often run initially with literature derived input values. However, the model can be made more site-specific by the collection of site-specific ingestion rates, diet composition, and habitat parameters.

In Table 7-1 (Section 7.1.1) the costs to run SEEM for the demonstration site are summarized along with other details that influence cost. In this section, we discuss the cost drivers and how data availability affects the overall cost of model application.

With respect to replacing another technology or methodology, SEEM was designed to replace or enhance the traditional use of a non-habitat-specific site-wide statistic for risk estimation. The cost of improving this estimate is the additional data required to characterize the habitat. Most risk assessments include some review of habitat even if the risk calculations do not explicitly consider habitat. SEEM utilizes and enhances data commonly collected for ecological risk assessments and remedial studies. In Table 7-2, we provide a summary of the costs for different levels of effort.

Table 7-2. Summary of Cost Ranges for SEEM Applications.

Cost Element	Components	Cost Element and Ranking	
Site Review	• Characterize the site based on background documents • Identify key species • Define modeling boundary	Background site studies and maps readily available Limited or very old site studies available	Low Cost High Cost
Assemble Model Inputs – Chemical Data	• Assemble chemical concentration data • This can be a highly variable component depending on data sources • Data may be in electronic table format handed off to the modeler or directly measured field data • In many cases this involves preparing already electronically obtained data (not collection and analysis of field samples) • Also note that in order to convert point data into polygons some form of interpolation may be completed	Chemical data with limited gaps available electronically – data covers full study area, no spatial averaging needed Hard copy chemical data available only – gaps in background areas; basic spatial averaging needed Limited old chemical data available – field study required; spatial averaging required	Low Cost Moderate Cost High Cost
Assemble Model Inputs – Species Exposure Values	• Inputs include factors such as bioaccumulation factor, ingestion rates, diet items, and percent in diet • In most cases the inputs are gathered from readily available literature sources • Exposure inputs measured directly are preferred, but higher costs are incurred (e.g., diet composition, percent soil in the diet)	Literature derived inputs Field study determined inputs	Low Cost High Cost

Cost Element	Components	Cost Element and Ranking	
Assemble Model Inputs – Habitat Suitability	• This component consists of identifying habitat/cover/land-use types and then ranking the suitability with respect to use by each of the selected receptors • This is another input that can be highly variable depending on the source – direct versus indirect observation • A direct field assessment of the habitat might vary from a qualitative report back from a field crew collecting samples, to a formal quantitative habitat assessment • Indirect field assessments use the power of satellite and aerial imagery and remote sensing expertise (e.g., combined with a state agency's GIS land use maps) • Generally users locate digital maps and satellite/aerial photography for no cost	Remote sensing habitat survey – not field visit Qualitative – direct observation of habitat paired with remote maps Detailed quantitative habitat survey – measured metrics	Low Cost Moderate Cost High Cost
Insert Model Inputs Using Guided Input Steps in SEEM	• The one time-consuming part of data entry is drawing the polygons in the polygon tool. Future versions will allow for direct import of shape files. This step takes 80% of the effort in this step • SEEM XL create review efficiencies	<5 total chemical and habitat polygons >5 total chemical and habitat polygons	Low Cost High Cost
Run SEEM	• The time required to run the model will depend on the number of individuals selected in the model population • Model runs must be completed independently for each receptor • It is important to organize the outputs and name the output files clearly to avoid future confusion • Iterative runs can be made for sensitivity testing • Since all data have already been entered, this step has a low time/cost	Run model (final cost depends on number of iterations)	Low Cost

8.0 IMPLEMENTATION ISSUES

Based on numerous workshops, the feedback has been positive regarding the accessibility and utility of SEEM, but implementation challenges remain. Some include:

- Continuing hesitation to use SEEM model results in site assessment reports
- Hesitation by regulatory and scientific community to make final decisions based on the result outputs
- Incremental model improvements lead to a better model, but preferred design updates are not made regularly due to lack of maintenance funding
- In custom models there is the hurdle of tracking programming software updates through time and remedying bugs that result from software upgrades
- There are benefits in terms of implementation to being a standalone model, but there is an increasing demand for linkage to GIS software and issues installing the software on machines with specific security configurations

We have sought to manage these issues as follows:

- As part of this project we held an expert conference to discuss ways to encourage greater application of spatial models in regular practice. We generated two publications (Hope *et al.*, 2011; Wickwire *et al.*, 2011), organized, and led a session at SETAC 2012 specifically focused on the power and value of these models
- With this project, SEEM has been moved to a more modern platform and the programming notation was updated and clarified. Though the change to a new programmer required a background review of an individual outside the project, the result was a more flexible and accessible platform. Response time for reports of computer challenges has been reduced
- Finally, we have started development of a SEEM tool integrated into a freely available GIS platform. This effort was outside of the scope of this project so it is not ready for wide distribution, but based on input from the programmer it became evident that the next incremental update must include GIS. This step would greatly increase the flexibility of future updates. A brief introduction to SEEM-GIS is provided below. SEEM-GIS is a complete implementation of animal movement and exposure algorithms as a plugin for the free, open-source GIS software SAGA (System for Automated Geoscientific Analyses). Users simply prepare two raster grids of the same dimensions in their GIS software of choice, with cell values representing chemical concentrations and habitat suitability. Grids may be arbitrarily sized and are not restricted to the

25 x 25 cells used by standalone SEEM following interpolation of polygons. SAGA can easily import all common raster file formats, and users enter the simulation parameters for SEEM in an easy-to-use settings dialog with context-sensitive help for parameters. After the simulation is complete SEEM-GIS provides a table of statistics by individual receptor, and a variety of visualization and export options for the simulated foraging positions. The SEEM algorithm has been rewritten in cross-platform C++ for speed, accuracy, and ease of integration in other GIS frameworks such as ArcGIS and Quantum GIS. Simulation results have been validated against the existing algorithms used in standalone SEEM

9.0 REFERENCES

Beyer WN, Connor EE, Gerould S. Estimates of soil ingestion by wildlife. Journal of Wildlife Management. 1994; 58(2):375-382.

Blair WF. Notes on home ranges and populations of the short-tailed shrew. Ecology. 1940; 21: 284-288.

Buckner, CH Populations and ecological relationships of shrews in tamarack bogs of Southeastern Manitoba. J. Mammal. 1966; 47: 181-194.

Buekers J, Redeker ES, Smolders E. Lead toxicity to wildlife: derivation of a critical blood concentration for wildlife monitoring based on literature data. 3431-8. In: The Science of the total environment. 2009; 407 (11).

Freshman JS, and Menzie CA Two wildlife exposure models to assess impacts at the individual and population levels and the efficacy of remediation. Human Ecol. Risk Assess. 1996; 2:481-498.

General Physics Corporation. Remedial Investigation Report, Other Edgewood Areas Study Area, Gun Club Creek Investigation Area (EAOE19 and EAOE38). Prepared by: General Physics Corporation for the U.S. Army Garrison, Aberdeen Proving Ground, MD. October 2009; Internal Draft. GP-R-123EO9022.

Hope, BK. Generating Probabilistic Spatially-Explicit Individual and Population Exposure Estimates for Ecological Risk Assessments. Risk Analysis. 2000; 20(5):573-589.

Hope, BK. A Case Study Comparing Static and Spatially-explicit Ecological Exposure Analysis Methods. Risk Analysis. 2001; 21(6):1001-1010.

Hope, BK. Performing spatially and temporally explicit ecological exposure assessments involving multiple stressors. Human and Ecological Risk Assessment. 2005; 11 (3): 539–565

Hope BK, Wickwire T, Johnson MS. The Need for Increased Acceptance and Use of Spatially-explicit Wildlife Exposure Models. Integrated Environmental Assessment and Management. 2011; 7(2): 156-157.

Johnson MS, Wickwire WT, Quinn MJ, Ziolkowski DJ, Burmistrov D, Menzie CA, Geraghty C, Minnich M, Parsons PJ. Are songbirds at risk from lead at small arms ranges? An Application of the Spatially-explicit Exposure Model (SEEM). Environ Toxicol Chem. 2007; 26(10): 2215-2225.

Loos M, Schipper AM, Schlink U, Strebel K, Ragas AMJ. Receptor-oriented approaches in wildlife and human exposure modeling: A comparative study. Environmental Modeling Software. 2010; 23:369-382.

McManus JJ. Bioenergentics and water requirements of the redback vole, *Clethrionomys gapperi*. J Mammal. 1974; 55(1):39-44.

Nagy KA, Girard IA, Brown TK. Energetics of free-ranging mammals, reptiles, and birds. Annual Review of Nutrition. 1999; 19:247-277.

Parsons PJ and Slavin W. A rapid Zeeman graphite furnace atomic absorption spectrometric method for the determination of lead in blood. Spectrochim Acta B. 1993; 48:925-939.

Platt WJ. The social organization and territoriality of short-tailed shrew (*Blarina brevicauda*) populations in old-field habitats. Anim. Behav. 1976; 24: 305-318.

Sample BE and Suter GW. Estimating Exposure of Terrestrial Wildlife to Contaminants. ORNL Oak Ridge National Laboratory (U.S.). ES/ER/TM-125. SEEM. 2013. Spatially-explicit Exposure Model (SEEM), User's Manual. 1994; Version 4.2. Draft.

Sibson, R. "A Brief Description of Natural Neighbor Interpolation," Chapter 2 in Interpolating Multivariate Data, 21–36. John Wiley & Sons: New York, 1981.

Talmage SS, and BT Walton. Food chain transfer and potential renal toxicity of mercury to small mammals at a contaminated terrestrial field site. Ecotoxicology. 1993; 2:243-256 (as cited in Sample BE and Suter GW, 1994).

Tannenbaum LV, Johnson MS, Bazar M. Application of the hazard quotient method in remedial decisions: a comparison of human and ecological risk assessments. Human and Ecological Risk Assessment. 2003; 9:387-401.

URS. 2009. Final Work Plan, Sampling and Analysis Plan, and Project Management Plan, Volume I of III, Range 17 – Trap and Skeet Site (FGGM 94), Patuxent Research Refuge, Laurel MD. Prepared by: URS Group, Inc. Prepared for: US Army Corps of Engineers, Baltimore District.

U.S. Army BTAG. 2002a. (January). Technical Document for Ecological Risk Assessment: Planning for Data Collection. SFIM-AEC-ER-TR-2002017. U.S. Army Biological Technical Assistance Group, U.S. Army Environmental Center, Aberdeen Proving Ground, MD. http://aec.army.mil/usaec/cleanup/ecorisk01-0102.pdf

U.S. Army BTAG. 2002a. (February). Technical Document for Ecological Risk Assessment: Selection of Assessment and Measurement Endpoints for Ecological Risk Assessment. SFIM-AEC-ER-TR-2002018. U.S. Army Biological Technical Assistance Group, U.S. Army Environmental Center, Aberdeen Proving Ground, MD. http://aec.army.mil/usaec/cleanup/ecorisk02-0202.pdf

U.S. Army BTAG. 2005b. (August). Technical Document for Ecological Risk Assessment: Process for Developing Management Goals. U.S. Army Biological Technical Assistance Group,

U.S. Army Environmental Center, Aberdeen Proving Ground, MD. http://aec.army.mil/usaec/cleanup/btag00.html

U.S. Army BTAG. 2005b. (April). Technical Document for Ecological Risk Assessment: A Guide to Screening-Level Ecological Risk Assessments. U.S. Army Biological Technical Assistance Group, U.S. Army Environmental Center, Aberdeen Proving Ground, MD. http://aec.army.mil/usaec/cleanup/btag00.html

U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). 2004. Development of Terrestrial Exposure and Bioaccumulation Information for the Army Risk Assessment Modeling System (ARAMS). U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) Contract Number DAAD050-00-P-8365, Aberdeen Proving Ground, MD, January 2006.

U.S. EPA. Wildlife Exposure Factors Handbook. 1993. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/R-93/187.

U.S. EPA. Guidelines for Ecological Risk Assessment. Final. 1998; EPA/630/R-95/002Fa. U.S. Environmental Protection Agency, Washington, DC. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12460

U.S. EPA. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. Interim Final. 1997; EPA 540-R-97-006/OSWER 9285.7-25/PB97-963211. US Environmental Protection Agency, Solid Waste, and Emergency Response, Washington, DC.

U.S. EPA. Ecological Soil Screening Levels for Lead. Interim Final. 9285: 7-70. Von Stackelberg K, Wickwire WT, Burmistrov D. Spatially-explicit exposure modeling tools for use in human health and ecological risk assessment: SEEM and FISHRAND-Migration. pp. 279–288. In: Environmental Exposure and Health, 2005. Aral MM, Brebbia CA, Maslia ML, Sinks T (Eds), United Kingdom: WIT Press.

U.S. FWS. 2009. Addendum To the baselines ecological risk assessment for the Eureka Mills Site, Eureka, Utah. West Valley City (Utah): U.S. Fish and Wildlife Service, Region 6, Utah Field Office.

von Stackelberg K, Wickwire WT, Burmistrov D. Spatially-explicit exposure modeling tools for use in human health and ecological risk assessment: SEEM and FISHRAND-Migration. pp. 279–288. In: Environmental Exposure and Health, 2005. Aral MM, Brebbia CA, Maslia ML and Sinks T (eds), United Kingdom: WIT Press.

Watson, D.Contouring: A Guide to the Analysis and Display of Spatial Data. Pergamon Press: London, 1992.

Wickwire WT and Menzie CA. New approaches in ecological risk assessment: Expanding scales, increasing realism, and enhancing causal analysis. Human and Ecological Risk Assessment 2003; 9:1411–1414.

Wickwire WT, Menzie CA, Burmistrov D, Hope BK. Incorporating spatial data into ecological risk assessments: the Spatially-explicit Exposure Model (SEEM) for ARAMS. Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities, and Biodiversity Enhancement Practices; ASTM STP 1458. In: Kapustka LA, Galbraith H, Luxon M, Biddinger GR (eds), 2004; ASTM International, West Conshohocken, PA.

Wickwire T, Johnson MS, Hope BK, Greenberg MS. Spatially-Explicit Ecological Exposure Models: A Rationale for, Path Toward Their Increased Acceptance, and Use. Integrated Environmental Assessment and Management. 2011; 7(2): 158–168.

Wickwire, WT, Menzie CA, Burmistrov D, Hope BK. Incorporating spatial data into ecological risk assessments: the Spatially-explicit Exposure Model (SEEM) for ARAMS. Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities, and Biodiversity Enhancement Practices; ASTM STP 1458. Kapustka LA, Galbraith H, Luxon M, and Biddinger GR (Eds). 2004; ASTM International, West Conshohocken, PA.

Wolff, JO. Behavior. In: Tamarin, RH, ed. Biology of New World *Microtus*. Spec. Publ. Am. Soc. Mammal. 1985; 8: 812-844 (as cited in Sample BE and Suter GW. 1994).

APPENDICES

Appendix A: Points of Contact

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