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Uncertainty analysis in ecological risk assessment modeling

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ABSTRACT

UNCERTAINTY ANALYSIS IN ECOLOGICAL RISK ASSESSMENT MODELING

by

Tepwitoon Thongsri

A probabilistic approach employing Monte Carlo simulations for assessing parameter and risks as probabilistic distributions was used in an ecological risk assessment (ERA) model to characterize risk and address uncertainty. This study addresses the following sources of uncertainty: parameter inputs in the ERA models, risk algorithms and uncertain input concentrations. To achieve this objective, both sensitivity and uncertainty analyses are being conducted. Monte Carlo simulations were used for generating probabilistic distributions of parameter and model uncertainty. All sensitivity, uncertainty, and variability analyses were coded in Visual Basic as part of the ERA model software version 2001, which was developed under the Sustainable Green Manufacturing (SGM) program. This simulation tool includes a Window's based interface, an interactive and modifiable database management system (DBMS) that addresses the food web at trophic levels, and a comprehensive evaluation of exposure pathways. To verify this model, ecological risks from Cr, Ta, Mo and DU exposure at the U.S. Army Yuma Proving Ground (YPG) and Aberdeen Proving Ground (APG) were assessed and characterized.

For the case of DU exposure to YPG terrestrial plants, the overall distributions for DU uptake for plants suggest 90% likelihood in reduction in root weight. For most terrestrial animals at YPG, the dose is less than that resulting in a decrease in offspring.

At APG, DU exposure potentially poses little risk for terrestrial animals, which is no observable impact on receptor's reproduction or development. DU potentially poses lower risks to aquatic species at APG as well. The overall risk posed by the metals followed the order of Mo>Cr>Ta for both YPG and APG sits. Blacktailed-jackrabbits, lesser long-nosed bats, mule deer and cactus mice, at YPG site, are expected to have a reduction in size and weight of offspring. Terrestrial plants are likely to exhibit a reduction in root weight. For APG site, the vulnerable receptors are white-footed mice, white-tailed deer, and cottontail rabbits. For terrestrial plants, the risk result suggests a reduction in root weight. Aquatic species did not show any observable risk from Mo, Cr, and Ta in the terms of survival, growth and mortality.

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by

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This dissertation is dedicated to
my beloved parents for their constant inspiration

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CHAPTER 1

INTRODUCTION

The ecological risk assessment model (ERA 2001 Beta1.4) was developed as part of the Department of Defense "Sustainable Green Manufacturing" program. It was based on a preliminary evaluation of the existing eco-risk models. ERA 2001 Beta1.4 includes a Windows interface, an interactive database management system (DBMS), and a comprehensive evaluation of the exposure pathways (Lu, 2001). In this model, each mathematical equation for an exposure incorporates species-specific information on the diet composition, body weight, home range, food and water ingestion rates, and incidental ingestion rates of the environmental media. All equations are presented in Appendix A.

There are two types of exposure assessments in this model: aquatic and terrestrial; both types include animal and plant exposure. The most complicated model among these is that of terrestrial animal exposure, which is due to the food web that accounts for the relationships between predator and prey. As such, the accumulated concentration in each level of the food web is included in assessing higher tropic levels. In all exposure estimations, the assessor employs equations, associated parameters, and contaminant concentrations. Each of these aspects has uncertainty and variability, which must be included in the risk assessment. The objective of this dissertation is to identify sources of uncertainty in ecological risk assessment and present and develop a method to address uncertainty analysis. A thorough understanding of the principles and basics in uncertainty

will lead to a comprehensive analytical approach and complete uncertainty identification in the assessment process. Therefore, in this study, methods to account for both uncertainty and variability will be presented. Initially, the types of uncertainty will be discussed and will be followed by approaches to implement and assess their contribution to exposure estimates.

Organization of this dissertation will include: Chapter 1, an introduction defining relevant terms and principles needed to perform uncertainty analysis; Chapter 2, describing necessary tools; Chapter 3, approach for uncertainty analysis in ERA models; Chapter 4, ERA model code modification; Chapter 5, model parameterization; Chapter 6, parameter sensitivity analysis and model verification; Chapter 7, demonstration of risk evaluation; and Chapter 8, conclusions and recommendations for future work.

1.1 Definition of Variability and Uncertainty

The U.S. EPA (1997e) has advised the risk assessor to distinguish between variability and uncertainty. Uncertainty represents a lack of knowledge about factors affecting exposure or risk, whereas variability arises from true heterogeneity across people, places or time. In other words, uncertainty can lead to inaccurate or biased estimates, whereas variability can affect the precision of the estimates and the degree to which they can be generalized. The following discussion will provide more information on variability and uncertainty.

Variability refers to observed differences attributable to *true heterogeneity* or diversity in a population or exposure parameter (U.S. EPA, 1997e). Sources of variability are the result of natural random processes and stem from environmental, lifestyle, and

genetic differences among humans. Examples include receptor physiological variation (e.g., natural variation in bodyweight, breathing rates, water intake rates), weather variability, and variation in soil types in the environment. Variability is usually not reducible by further measurement or study but it can be better characterized (Peterman and Anderson, 1999).

Uncertainty refers to *lack of knowledge* about specific factors, parameters, or models (Smith, 2002; U.S. EPA, 1997b). Uncertainties in exposure models can include how well the exposure model or its mathematical expression approximates the true relationships in the field as well as how realistic the exposure model assumptions are for the situation at hand (U.S. EPA, 1993a). According to U.S. EPA (1998a), uncertainty evaluation is a theme that should be addressed throughout the analysis methodology. What is known and not known about exposure and effects in the system of interest should always be taken into account. Uncertainty analyses increase the credibility of assessments by explicitly describing the magnitude and direction of uncertainties, and by providing the basis for efficient data collection or application of refined methods (Shakshuki *et al.*, 2002). The sources of uncertainty are relevant to the analysis of ecological exposure and effects (U.S. EPA, 1998a; Vermeire *et al.*, 2001).

Sources of uncertainty that are encountered when evaluating information include unclear communication of the data or its manipulation and errors in the information itself. These are usually characterized by critically examining the sources of information, and documenting the decisions made when handling them. Sources of uncertainty that primarily arise when estimating the value of a parameter include variability and uncertainty about a quantity's true value (U.S. EPA, 1998a; 1999b). Sources of

uncertainty that arise primarily during model development and application include process model structure and the relationships between variables in empirical models (U.S. EPA, 1998a). Uncertainty in process or empirical models can be quantitatively evaluated by comparing model results to measurements taken in the system of interest or by comparing the results of different models.

Methods for analyzing and describing uncertainty can range from simple to complex (Smith, 2002; Hoffman *et al.*, 1999). When little is known, a useful approach is to estimate exposure and effects based on alternative sets of assumptions. Results can be presented as a series of point estimates with different aspects of uncertainty reflected in each. For models, sensitivity analysis can be used to evaluate how model output changes with changes in input variables, and uncertainty propagation can be analyzed to examine how uncertainty in individual parameters can affect the overall uncertainty in the results (Bedford and Cooke, 2001; U.S. EPA, 1998a). The following section will provide more details about sensitivity analysis.

1.2 Sensitivity Analysis

Sensitivity analysis is a powerful tool to identify the main sources of uncertainty (Jager *et al.*, 2001). Sensitivity analysis is the process of changing one variable while leaving the others constant and determining the effect on the output. The procedure involves fixing each uncertain quantity, one at a time, and then computing the outcomes for each combination of values (Dubus and Brown, 2002). These results are useful in identifying the variables that have the greatest effect on exposure and to help focus further information gathering. The results do not provide any information about the probability

of a quantity's value being at any level within the range; therefore, this approach is most useful at the screening level when deciding about the need and direction of further analyses. Sensitivity analysis is sometimes a by-product of a Monte Carlo uncertainty analysis (Smith, 2002). For example, if interest is in the sensitivity of the response to changes in variables, the values of the variables are selected using a probability method and then run through the model. The result is a set of input and output quantities. The importance of a variable is measured by the correlation or partial correlation between the variable and the response. A variable with the greatest (positive or negative) correlation indicates the variable with the greatest sensitivity (Smith, 2002).

1.3 Analytical Uncertainty Propagation

Uncertainty propagation involves examining how uncertainty in individual parameters affects the overall uncertainty of the exposure assessment. Intuitively, it seems clear that uncertainty in a specific parameter may propagate very differently through a model than another variable having approximately the same uncertainty. Some parameters are more important than others, and the model structure is designed to account for the relative sensitivity. Thus, uncertainty propagation is a function of both the data and the model structure (U.S. EPA, 1992; U.S. EPA, 1997e). Accordingly, both model sensitivity and input variances are evaluated in this procedure. Application of this approach to exposure assessment requires explicit mathematical expressions of exposure, estimates of the variances for each of the variables of interest, and the ability either analytically or numerically to obtain a mathematical derivative of the exposure equation. Probabilistic

distribution is one of methods to perform an uncertainty propagation, which will be discussed in the next section.

1.4 Probabilistic Uncertainty Analysis

Probabilistic analysis can be used to propagate uncertainties in model inputs and to estimate uncertainties in model outputs. Unlike sensitivity analysis, probabilistic analysis yields quantitative insight into both the possible range and the relative likelihood of values for model output. The purpose of probabilistic analysis is to characterize variability and uncertainty in model outputs. Another purpose is to identify key sources of uncertainty and variability that can be the focus of future data collection, research, or model development activity (Cullen and Frey, 1999).

Knowledge of the variability and uncertainty associated with the input distributions has an impact on the output result. Variability is an inherent factor that must be addressed in the exposure/risk assessment procedure while uncertainty can usually be reduced only by additional data (Mitchell, 2002). Therefore, the appropriate tools to handle uncertainty must be used. Probabilistic distributions have been used as a tool to qualify uncertainty in predictions of risks to humans and ecological receptors (Frey and Rhodes, 1998). The input variables are considered random, resulting in risk presented as a probability distribution for the given exposure. The Monte Carlo analysis is a useful method for propagating input data error in models (US.EPA, 1997b; Vardoulakis *et al.*, 2002). To apply Monte Carlo simulations, a distribution must be specified that quantitatively expresses the state of knowledge about each parameter. The distributions characterize the degree of belief that the true but unknown value of a parameter lies

within a specified range of values for that parameter (Warren-Hicks *et al.*, 2002). A distribution of predicted values will reflect the overall uncertainty in the inputs. More details of probabilistic distribution and Monte Carlo simulation method will be discussed in the next Chapter.

CHAPTER 2

TOOLS FOR PROBABILISTIC ANALYSIS

Two key tools for conducting probabilistic analysis in environmental risk assessments are the use of probabilistic distributions to delineate the extent of uncertainty and the application of the Monte Carlo simulation method to generate viable data sets. Together they produce a coherent picture for the assessor to evaluate the impact of uncertainty on environmental risk assessment results. Probabilistic distributions more clearly depict the true nature of each input variable; this produces greater realism within an analysis model. The Monte Carlo simulation method enables an evaluation of the output of the model by random sampling from the distribution assigned to each one of the uncertain input variables (NCRP, 1999). The advantage of Monte Carlo simulations is that deterministic simulations are repeated in a manner that yields important insights into the sensitivity of the model to variations in the input parameters, as well as into the likelihood of obtaining any particular outcome (Sanga *et al.*, 2001). The Monte Carlo method also allows the user to use any type of probability distribution for which values can be generated on a computer (Warren-Hicks *et al.*, 2002). The following sections will provide a description of the approaches for applying probabilistic distributions and the Monte Carlo method.

2.1 Probabilistic Distribution

A probabilistic distribution is a description of the probabilities of all possible values in a sample space. A probability model is typically represented mathematically as a probability distribution in the form of either a probability density function (PDF) or

cumulative distribution function (Kelly and Campbell, 2000; Vining, 1998). By using the probabilistic approach, we can employ a probability distribution to characterize uncertainty and/or variability in some or all model inputs (Thompson, 2002; Thompson and Graham, 1996). When input uncertainty is characterized by a probability distribution, the predicted uncertainty is characterized by the induced prediction distribution (McKay *et al.*, 1999).

Probabilistic risk assessment is a general term for risk assessments that use probability models to represent the likelihood of different risk levels in a population or to characterize uncertainty in risk estimates (Thompson and Graham, 1996). For example, in ecological risk assessments, probability distributions may reflect variability or uncertainty in exposure or toxicity. In human health risk assessments, probability distributions for risk reflect variability or uncertainty in exposure (Freyerweather *et al.*, 1999). A probabilistic approach also quantifies uncertainty. Its output can provide a quantitative measure of the confidence in the risk estimate (Burmaster and Willson, 1998; Thompson, 2002).

Probabilistic analysis techniques are statistical tools for analyzing variability and uncertainty in risk assessments, which are supported by adequate data and credible assumptions (U.S. EPA, 1997b). Probabilistic techniques can enhance risk estimates by more fully incorporating available information concerning the range of possible values that an input variable could take, and weighting these values by their probability of occurrence (Havens *et al.*, 2002;Carbone *et al.*, 2002). This method also permits the risk assessor to assess the range of exposures and their associated probabilities, which result from combinations of the various residue levels and consumption patterns. The resulting

output of a probabilistic determination is a distribution of risk values with probability assigned to each estimated risk (Wenning, 2002; U.S. EPA, 1998c; NCRP, 1999).

In the past, risk assessment methods have focused on a single indicator of risk. The single indicators of risk are useful as a screening tool that approximate remote, although plausible, worse case scenarios for subpopulations of highly exposed individuals (Rai *et al.*, 2002). However, this approach does not consider the full range of available information, nor does it explicitly account for important sources of uncertainty in estimating risks (Yegnan *et al.*, 2002; Lahkim and Garcia, 1999). In addition, point estimates of risk may convey an unnecessary sense of accuracy and can lead to inconsistencies in making comparisons among risks (Thompson and Graham, 1996). Furthermore, relying on a single value estimate of risk for remedial typically results in an over estimation of costs (Lahkim and Garcia, 1999;U.S. EPA, 1992).

On the other hand, probabilistic risk assessment differs from the point estimate approach by allowing a value to be chosen from a distribution of plausible values for an exposure variable. Variables that can assume different values for different people are referred to as random variables. In probabilistic risk assessment, one or more (random) variables in the risk equation are defined mathematically by probability distributions. Similarly, the output of a probabilistic risk assessment is a range or distribution of risks experienced by the various members of the population of concern (Warren-Hicks and Moore, 1998). Regarding uncertainty analysis, the use of probabilistic methods to propagate variability and uncertainty through risk models has advantages over point estimate approaches. Specifically:

1) Probabilistic methods can provide a more robust method of quantifying confidence in risk estimates than the point estimate approach (Burmaster, 1998). Monte Carlo simulation can be used to combine distributions of uncertainty for multiple input variables in a single simulation. By contrast, point estimate approaches combine point estimates of uncertainty in separate calculations, a technique that can yield estimates of plausible bounds for risk, but cannot yield an estimate of the upper and lower 95% confidence limits (NCRP, 1999; U.S. EPA, 1997d: 1999b).
2) The probabilistic method uses full information methods by including all the information available about the variability and the uncertainty inherent in the assessment (Carbone *et al.*, 2002). In the point estimate approach, the risk assessor discards most of the information about the variability and uncertainty in a phenomenon to pick one point value (Rai *et al.*, 2002).
3) Probabilistic methods are reliable since they incorporate the full range of values that a variable may assume (Solomon and Sibley, 2002). On the other hand, a risk assessor working in the deterministic method is required to use many high point values to exaggerate a problem so the risk assessor can ignore the complexities and cost-effectiveness of a remediation (U.S. EPA, 1999b).
4) Probabilistic methods estimate the population distribution of the output; therefore, the probabilistic distributions of the model variables are good representations of the population (Moschandreas and Karuchit, 2002).
5) Probabilistic methods save money. Full information risk assessments may cost more than screening analyses using point values. But probabilistic assessments

can be less stringent for fully protective cleanup targets at remediation sites (U.S.EPA, 1999c). Since cleanup costs often rise asymptotically with decreasing cleanup targets, probabilistic assessments protect people and have high internal rates of return (U.S. EPA, 1999b; 1999c).

As discussed earlier, in the point estimate approach, parameter uncertainty is addressed in a qualitative manner for most variables. In a probabilistic approach, a probability distribution for risk will represent either variability or uncertainty; depending on how the distributions for the input variables are characterized (Warren-Hicks and Moore, 1998). If exposure variability is characterized using probability distributions, the risk distribution represents variability. If input distributions represent uncertainty in estimates of central tendency (e.g., arithmetic mean), the output distribution represents uncertainty in the central tendency risk (U.S. EPA, 1999a; 1999b). By separately characterizing variability and model uncertainty, the output from a probabilistic risk assessment will be easier to understand and communicate (Thompson, 2002; Von Stackkelberg *et al.*, 2002).

Probabilistic distribution methods have been employed in human, ecological, and technological risk assessments to qualify uncertainties in predictions of risks (Solomon and Sibley, 2002; Frey and Rhodes, 1998). The following paragraphs present some studies, which have used the probabilistic distribution approach.

Dabberdt and Miller (2000) used a probabilistic method for quantifying the uncertainty related to model predictions for an accidental release application. An ensemble set of 162 simulations was created by specifying a best estimate together with

two additional values that bound the likely range of uncertainty in estimating four input parameters. Vermeire *et al.* (2001) compared the results between the probabilistic risk assessment and the deterministic risk assessment of dibutylphthalate (DBP) in humans. According to the uncertainty analysis performed the probability is approximately 20% that the total human dose is lower than the deterministic estimate of DBP exposure (93 μg/kg-d). From their discussion, a probabilistic risk assessment covered both the exposure and the effects assessments; also it allows determination of the range of possible outcomes and their likelihood. It, therefore, better informs both risk assessors and risk managers than the deterministic approach.

Lohman *et al.* (2000), in studying the impact of mercury on the ecological system for Lake Mitchell, used probability distributions to characterize the uncertainties associated with the model inputs and to calculate the resulting probability distribution for the model output variables. They found that the large uncertainty sources were mercury emission speciation, lake pH, and sediment burial rate. Hope (1999) applied the probabilistic distribution method to estimate the risk from polychlorinated biphenyls at former industrial landfills in Crab Orchard National Wildlife Refuge. As Hope mentioned, a probabilistic approach gives a greater insight into the consequences of uncertainty and variability inherent in data and risk analyses.

Jager *et al.* (2001) demonstrated either deterministic or probabilistic methods are feasible to use as a tool to assess the risk for new and existing chemicals in the European Union. From their case study, the deterministic risk quotients turned out to be worst cases at generally higher than the 95^{th} percentile of the probability distributions. Mitchell and Campbell (2001) also agreed that when there are adequate data, the probabilistic

assessment is more appropriate to use as a tool to characterize input parameters in an operator and residential exposure assessment. Wenning (2002) included a probability analysis to derive the probability density functions describing the range of plausible exposures associated with different pathways of risk assessment of polybrominated diphenyl ether isomers in aquatic biota and human breast milk.

Sanga *et al.* (2001) evaluated uncertainties in dietary methyl mercury (MeHg) exposure modeling which provided some insight into the utility of biomarkers of exposure and dietary recall records for assessing MeHg exposure. From their work, a probability distribution was assigned to describe the standard deviation demonstrating uncertainty in the mean. Monte Carlo simulation was conducted for each input variable by randomly sampling a single value from a normal distribution representing the lack of knowledge in the mean. This developed a family of cumulative distribution functions (CDFs) representing lack of knowledge about the true population heterogeneity distribution.

Probabilistic analysis is also gaining more attention in the field of landslide hazard assessment due to the possibility of taking into account estimation uncertainties and spatial variability of geological, geotechnical, geomorphological and seismological parameters (Refice and Capolongo, 2002). Duzgun *et al.* (2002) applied a probabilistic method to perform an uncertainty analysis in the shear strength of rock discontinuities. Different sources and types of uncertainties associated with the discontinuity shear strength were identified and described with suitable probability distributions. As the results, the uncertainty or correction factors were established.

To perform a quantitative uncertainty analysis, probability distributions must be assigned to each of the uncertain parameters. The distributions must be used to reflect the degree of belief that the unknown value for a parameter lies within a specified range (Hoffman and Hammonds, 1994). When dealing with several different distributions, it is more efficient to use numerical methods (e.g., Monte Carlo analysis) to propagate uncertainty through a risk assessment model than to use various analytical methods (algebraic equations). The following section will provide more details on how to apply Monte Carlo simulation to the probabilistic distribution method.

2.2 Monte Carlo Simulation

Uncertainty and variability in the risk assessment process are often handled in a qualitative approach by tightening the acceptable risk level (Wong and Yeh, 2002). A better approach is to include uncertainty and variability explicitly in the risk assessment process by calculating the probabilistic distribution of the risk value (Mitchell and Campbell, 2001). Because the factors in the risk assessment may have different probability distributions and different degrees of certainty, the Monte Carlo simulation is usually used to evaluate the joint probability distribution for the risk value (Wong and Yeh, 2002).

Monte-Carlo techniques have been used since the 1940's when they were first developed by physicists working on the Manhattan project (Warren-Hicks *et al.*, 2002). Recently, Monte-Carlo techniques are widely applied to health and ecological risk assessments (Decisioneering, 2002). According to the U.S. EPA (1997e), interest in using Monte Carlo analysis for risk assessment has increased. This method has the advantage of

allowing the analyst to account for relationships between input variables and of providing the flexibility to investigate the effects of different modeling assumptions. The U.S. EPA (1998a) stated that such probabilistic analysis techniques as Monte Carlo analysis, given adequate supporting data and credible assumptions, can be viable statistical tools for analyzing variability and uncertainty in risk assessments.

The National Council on Radiation Protection and Measurements (NCRP) recommends Monte Carlo simulation as a tool to overcome problems with variance propagation equations for complex models (NCRP, 1996). Also, NCRP suggests that Monte Carlo calculations are more useful than analytical approaches to uncertainty analysis because analytical solutions based on variance propagation techniques provide only approximate probability or confidence intervals and can become very complicated and time- consuming for more involved risk analyses.

By using a Monte Carlo simulation in the probabilistic risk assessment, an exposure dose calculation is repeated thousands of times using statistical techniques to select random values for each exposure variable that is characterized by a probability distribution (Moschandreas and Karuchit, 2002; U.S. EPA, 1997b). In addition, information on the distribution (range and likelihood) of possible values for these parameters is produced (Havens *et al.*, 2002). The Monte Carlo technique has the advantage of being generally applicable, with no inherent restrictions on input distributions or input-output relationships, and of using relatively straightforward computations (NCRP, 1999; U.S.EPA, 1999b). The resulting output distribution reflects the range of exposure doses that may exist at the site for the population being considered (Yegnan *et al.*, 2002). This distribution of doses is then multiplied by the appropriate

toxicity values to obtain a distribution of risks (Warren-Hicks *et al.*, 2002). Also, Monte Carlo results can be used statistically to describe uncertainty and to quantify the degree of conservativeness used (Cullen and Frey, 1999). For better understanding, the Monte Carlo simulation process is described as follows.

The first step in a Monte-Carlo simulation is the construction of a model that accurately represents the problem. The makeup of the model usually entails a mathematical combination (addition, multiplication, logarithms, etc.) of the model input variables, which can be expressed as probability distributions (Cullen and Frey, 1999). Monte Carlo analysis is usually performed using a random sampling process. In this process, a random value is taken from the distribution specified for each uncertain model parameter, and a single estimate of the desired endpoint is calculated. This process is repeated for a specific number of samples or iterations. The result is an empirical approximation to the probability distribution of the model output or assessment endpoint (Havens *et al.*, 2002).

The input required for Monte Carlo simulations are the probability distributions for each parameter (Moschandreas and Karuchit, 2002). These distributions are obtained by extensive review of available literature and site-specific data. The result or output distribution of Monte Carlo simulation reflects the range and relative frequency of risks that may exist at the site for the population and the exposure-related activities being considered (U.S. EPA, 1997e). Thus, probabilistic risk assessment enables risk assessors to use statistical and mathematical techniques to obtain quantitative measures of both uncertainty and variability in risk estimates (Warren-Hicks *et al.*, 2002).

Specific values for the inputs are randomly assigned according to pre-selected distributions. A model is run repeatedly by applying random inputs from the parameter distribution (Cullen and Frey, 1999; Metzger *et al.*, 1998). The values of each of the uncertain input parameter are generated based on the probabilistic distribution for the parameter. If there are two or more uncertain input parameters, one value from each is sampled simultaneously for every repetition in the simulation. With many input variables, one can envision the Monte Carlo simulation as providing a random sampling from a space of m dimensions, where m is the number of random variables that are inputs to the model. Over the course of the simulation, sample sets of 100, 1000, and 5000 can be repeated for the evaluation. The result is a set of sample values for each of the model output variables, which can be treated statistically as if they were an experimentally or empirically observed set of data. These can be represented as a cumulative distribution function (CDF) or a probability density function (PDF) and summarized using typical statistics such as mean and variance. Also, the CDFs allow for quantitative insight regarding the percentile of the distribution (NCRP, 1996; Shakshuki *et al.*, 2002).

For better understanding, the process of a Monte Carlo simulation is illustrated in Figure 1.1. In its general form, the risk equation can be expressed as a function of exposure and toxicity variables (Pi): Risk(R) = f (P_1, P_2, ...P_n). Solutions for equations with PDFs are typically too complex for even an expert mathematician to calculate the risk distribution analytically. However, computers can provide reasonably close approximations of a risk distribution using numerical techniques (NCRP, 1996).

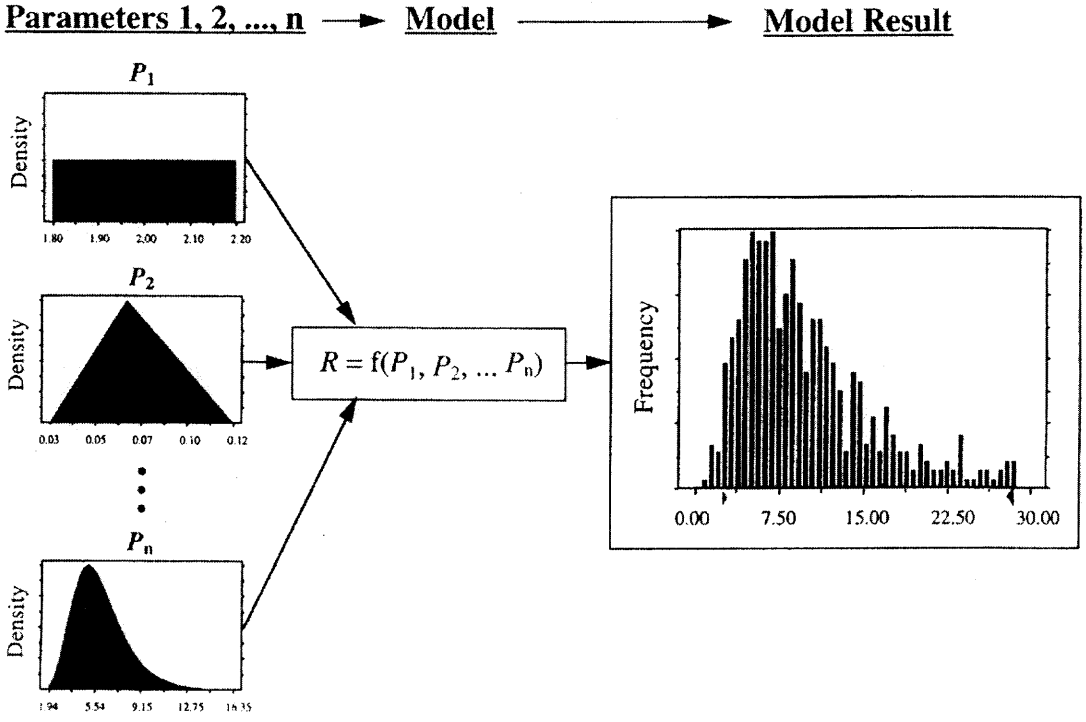


Figure 1.1 PDF Resulting from a Monte Carlo Simulation (NCRP, 1996).

This is illustrated here for the simplified case in which the assessment variables are statistically independent. In this case, the computer selects a value for each P_i at random from a specified PDF and calculates the corresponding risk. This process is repeated many times (e.g., 1000), each time saving the set of input values and corresponding estimate of risk. For example, the first risk estimate might represent a hypothetical individual who drinks 2 L/day of water and weighs 65 kg, the second estimate might represent someone who drinks 1 L/day and weighs 72 kg, and so forth. Each iteration of a Monte Carlo analysis represents a plausible combination of exposure and toxicity variables.

A convenient aid to understanding the Monte Carlo approach for quantifying variability is to visualize each iteration as representing a single individual and the collection of all iterations as representing a population (U.S. EPA, 1997e). In general, each iteration of a simulation should represent a plausible combination of input values, which may require using bounded or truncated probability distributions. A simulation yields a set of risk estimates that can be summarized with selected statistics (e.g., arithmetic mean, percentiles) and displayed graphically using the PDF and CDF for the estimated risk distribution (McKay *et al.*, 1999). This generates sets of product specific input files. Monte-Carlo techniques similarly cannot predict exactly which exposures will occur on any given day to any specific individual, but can predict the range of potential exposures in a large population and each exposure's associated probability (Warren-Hicks *et al.*, 2002). The following paragraphs provide some examples of researchers that applied a Monte Carlo simulation to their work.

Van Horssen *et al.* (2002) applied a Monte Carlo simulation to assess the model output error due to uncertainty in both regression coefficients and the explanatory variables. From their study, correlation between errors in regression coefficients and spatial auto-correlation in explanatory variables are accounted for in the Monte Carlo analysis. Therefore, the patterns of the relative contributions of uncertainty to the model uncertainty give information on the most effective way to reduce error, i.e. either by reducing uncertainty in the regression coefficients or in the interpolated input patterns (Van Horssen *et al.*, 2002).

In physics, model simulations are the basis for predicting the evolution of large-scale natural phenomena such the weather, ocean currents, and climate (Hanson, 1999). A Monte Carlo method is presented for propagating uncertainties in underlying physics models into uncertainties in simulation predictions. With the increasing reliance on simulation methods, it is becoming critically important to determine how well they predict actual physical phenomena. Uncertainty in simulation predictions has many sources, including the lack of knowledge of the underlying physics models, the variability of the initial geometry and materials, and the degree of variability in the physical phenomenon itself (Hanson, 1999). In a probabilistic approach to uncertainty analysis, uncertainties are expressed in terms of a probability density function (PDF) defined on the parameters.

National Council on Radiation Protection and Measurements (NCRP) used Monte Carlo simulation to calculate the doses from decay products (NCRP, 1999). To estimate the likely distributions of doses to a member of a critical population group for various nuclides and exposure pathways, a Monte Carlo analysis was carried out for each

radionuclide considered. Separate calculations were carried out for adults and for children for land-use scenarios where children might constitute the critical group. The Monte Carlo simulations provided a distribution of possible doses to a member of the critical group for each dose pathway as well as for the total dose from all pathways (McKone, 1994; Warrant-Hicks *et al.*, 2002). The distributions of doses were generally quite broad due to the large uncertainty in the average or central tendency of the various parameters entering into the dose determination.

Sanga *et al.* (2001) used Monte Carlo simulation to evaluate the uncertainties in methyl mercury (MeHg) concentrations found in blood and hair analyses as biomarkers of dietary MeHg exposure. They compared biomarker-based exposure estimates against those derived from dietary intake surveys based on data from populations in Bangladesh, Brazil, Sweden, and the United Kingdom. Monte Carlo simulation was conducted for each input variable by (1) randomly sampling a single value from a normal distribution representing the lack of knowledge in the mean, and (2) using the mean to develop a software-simulated distribution of 100 random values representing the population heterogeneity. From their results, the mean MeHg exposure distribution represents the best guess of the true mean cumulative distribution of population MeHg intake. Also, the inter-individual variation in human behavior should be carefully evaluated when estimating risk exposure.

Moore *et al.* (1999) estimated the risks of methylmercury and PCBs in mink and belted kingfishers. They conducted the Monte Carlo simulations to estimate total daily intakes of each contaminant and integrated the resulting distributions with their respective dose-response curves to estimate risks. Chaloupka (2002) also used the Monte

Carlo method to conduct uncertainty analysis and to estimate population growth given demographic parameters subject to sampling error and environmental stochasticity of green turtle population dynamics in the southern Great Barrier Reef, Australia. Based on his study, fertility and adult survival were the most important high-level parameters affecting population growth, where fertility is a function of fecundity and temporal variability in breeding likelihood.

Sonnermann *et al.* (2003) used a Monte Carlo simulation as a tool to assess the uncertainty in a life cycle inventory of electricity produced by a waste incinerator. A proper probability distribution was assigned to relevant parameters. The final results give the upper bound of possible errors, which a single estimate method could not provide.

Based on the literature review above, the probabilistic distribution method and the Monte Carlo simulation method will be used as tools to perform uncertainty analysis in ecological risk assessment models. Although the Monte Carlo process sounds simple, a number of potential problems must be recognized. A very important one is the selection of the distribution. This may involve extensive work on the part of the risk analyst because the distribution describes the uncertainty about the parameter value. The distribution is often based on the minimum, maximum, and mode of the expected parameter value. It is impossible to specify the distribution exactly. However, what is important is to choose distributions based on such properties, as whether the distribution is skewed or symmetric, whether it should be truncated, and whether extreme values should be allowed. Therefore, the criteria to select the distribution will be developed in a later Chapter.

2.3 Discussion

When performing uncertainty analysis with probabilistic distribution and Monte Carlo simulation methods in ecological or human risk assessment, all work in the literature review above used external software to perform their calculations. Widely used, currently available software includes Crystal Ball® (Decisioneering, 2002) and @Risk® (Palisade Corporation, 2002). For example, Crystal Ball® was employed to a probabilistic analysis of regional mercury impacts on wildlife (Lohman *et al.*, 2000). Another software, @Risk® was used to a screening level probabilistic assessment of mercury risks in Florida everglades food webs (Duvall and Barron, 2000). Crystal Ball® and @Risk® are both spreadsheet-based programs. They were originally designed mainly for business applications. Crystal Ball® is a user-friendly, graphically oriented forecasting and risk analysis program that takes into account the uncertainty of decision-making. Crystal Ball® 2000 analyzes the risks and uncertainties with Excel spreadsheet models (Decisioneering, 2002). @Risk® is a software system, which allows the decision-maker to explicitly include the uncertainty in estimate to generate results that show all possible outcomes. @Risk® is the risk analysis and simulation add-in for Microsoft Excel® and Lotus® 1-2-3. As an add-in, @Risk® becomes seamlessly integrated via a new toolbar and functions with a spreadsheet (Palisade Corporation, 2002).

However, these software are not specific for ecological risk assessment but can be applied to assess a risk in other fields such financial consulting, cost estimate consulting, market research, analyzing engineering projects, insurance etc. Therefore, when using one of these software packages, the user needs to be aware of how to apply these software functions to their work.

Another drawback is that when using the stand-alone risk analysis software, users need to re-create their model equations and their input parameter values in the software spreadsheet. These procedures consume time and are redundant work. Furthermore, in cases utilizing complex modeling, performing an uncertainty analysis in the spreadsheet is not practical, as it needs to account for excessive amounts of data. For example, the risk assessment in receptors according to contaminants in the trophic level of the food web requires the input of many data points from the various levels of the food chain. It becomes too time consuming to enter this data. Price also becomes a factor. The price of software is quite expensive; it costs $1685 for Crystal Ball®; $1395 for @Risk® software.

Therefore, in this study, combining the ecological risk assessment model (ERA) with the probabilistic distribution/Monte Carlo simulation method will be initiated. Model parameters and data are stored in the modifiable database management system (DBMS). This combination will provide an easy and appropriate way to perform uncertainty analysis in the ERA model utilizing the probabilistic distribution method.

As this Chapter provides tools that will be used to perform an uncertainty analysis, the next Chapter presents the hypotheses for uncertainty analysis in ERA models, which include problem formulation, approach, demonstration, areas of study, and contaminants of interest. Also the following Chapter will provide the approach to link parameter and model probabilistic distributions using Monte Carlo simulation method in the ERA model codes.

CHAPTER 3

APPROACH FOR UNCERTAINTY ANALYSIS IN ERA MODELS

3.1 Problem Formulation

When ERA models are used to determine the risk to receptors, the users will need to know the accuracy of their results. These models deal with parameter inputs from various sources such as characteristics of contaminants, receptors, and the ecosystem, as well as contaminant concentrations in the various media. The study will address the following uncertainty:

1) Parameter inputs (variability and uncertainty) in the ERA models;
2) Risk algorithms (model uncertainty); and
3) Input concentrations.

3.2 Methods

The following approach will be applied in this study. The details of the methodology for exposure model parameters will be discussed in the following section.

3.2.1 Variable Uncertainty

Due to the large number of parameters used in ERA models, it is advisable to identify those with the largest impact on the model results. For this reason sensitivity analysis will be carried out. Parameter sensitivity analysis is a tool that describes the significance of each parameter in the model. To determine the sensitivity of parameters within the

model, one parameter will be varied at random, while the remaining parameters are held at fixed value. Parameters of concern in this study are shown in Table 3.1.

3.2.2 Model Uncertainty

Uncertainty analysis of models will be propagated with the error from each parameter in parameter inputs. The probabilistic distributions will be used to demonstrate uncertainty of model outputs (result) or estimated exposure. Probabilistic distribution analysis emphasizes developing model input assumptions based on variable information and knowledge. Also, probabilistic distributions are subjective evaluations of parameters where the nominal value is considered as the most likely value. A Monte-Carlo simulation is simply one of several mathematical techniques for performing probabilistic risk assessments.

The Monte Carlo technique, as applied to exposure assessment, involves combining the results of hundreds or thousands of random samplings of values from input probability distributions in such a manner as to produce an output distribution, which reflects the expected range and frequency of exposures (Cullen and Frey, 1999; U.S. EPA, 1996b). Goodman (2002), Chaloupka (2002), and Shakshuki *et al.* (2002) also recommend probabilistic distribution methods as tools in approaching uncertainty analysis in ecological risk assessment. Thus, the probabilistic distribution method and the Monte Carlo simulation method will be used to analyze uncertainty in ERA models.

Table 3.1 Exposure Model and Parameters

Receptors	Exposure pathway	Equations	Parameters
Terrestrial plants	Root uptake from root-zone soil to roots	$C_{pr} = EC_{rzs} \times K_{ps1}$	C_{pr} = contaminant concentration in plant roots, mg/kg EC_{rzs} = contaminant concentration in root-zone soil, mg/kg K_{ps1} = plant-soil partition coefficient for root-zone soil to roots, mg/kg (soil)/mg/kg (roots)
	Root uptake from root-zone soil solution to roots	$C_{pr} = EC_{sw} \times RCF$	EC_{sw} = contaminant concentration in surface water in contact with roots, mg/L RCF = root concentration factor, L/kg
	Root uptake from root-zone soil to above-ground plant parts	$C_{pa} = EC_{rzs} \times (K_{ps2}, B_r, B_v)$	C_{pa} = Contaminant concentration in above-ground plant parts, mg/kg K_{ps2} = Plant-soil partition coefficient for root-zone soil to above-ground plant parts, mg/kg (soil)/mg/kg(above-ground plant) Br = Bioconcentration factor for nonvegetative plant parts, mg/kg (soil)/mg/kg (vegetative plant) B_v = Bioconcentration factor for vegetative plant parts, mg/kg (soil)/mg/kg (nonvegetative plant)
	Foliar uptake (vapor)	$C_{pa} = EC_{vap} \times K_{pa}$	K_{pa} = Plant-air partition coefficient for air to above-ground plant parts, m^3/kg

Table 3.1 Exposure Model and Parameters (continued)

Receptors	Exposure pathway	Equations	Parameters
Terrestrial animals	Direct absorption from dermal exposure	$ADD_{dcs} = [(SA \times AF \times P_{cs} \times EC_s \times CF \times \alpha_d) / BW) \times \theta \times \psi$ $C_{dc} = ADD_{dc} / .k_e$	ADD_{dc} = absorbed daily dose from dermal contact, mg/kg C_{dc} = contaminant body burden in receptor from dermal contact, mg/kg EC_s = contaminant concentration in soil, mg/kg SA = surface area of ecological receptor, cm^2 AF = soil-to-skin adherence factor, mg/ cm^2 P_c = fraction of receptor surface area in contact with soil per day, d^{-1} α_d = contaminant-specific dermal absorption factor, mg/kg (contaminant body burden) / mg/kg (absorbed daily dose) k_e = contaminant-specific depuration rate, d^{-1} BW = body weight of receptor, kg CF = conversion factor, 1×10^{-6} kg/mg θ = site use factor, (ratio of contaminant area to home range) ψ = seasonality factor; (fraction of time per year receptor occurs at site)

Table 3.1 Exposure Model and Parameters (continued)

Receptors	Exposure pathway	Equations	Parameters
Terrestrial animals	Inhalation of volatilized contaminants	$ADD_{iv} = [(IR_I \times EC_{va}) / BW] \times \theta \times \psi \times B_t$	ADD_{iv} = applied daily dose from inhalation of volatilized contaminants, mg/kg
		$C_{iv} = ADD_{iv} \times (\alpha_v / k_e)$	C_{iv} = contaminant body burden in receptor from vapor inhalation, mg/kg
			IR_i = inhalation rate, m^3/day
			B_t = fraction of day spent in burrow, hr/24hr
			EC_{vap} = concentration of volatilized contaminant in air, mg/ m^3
			α_v = inhalation absorption factor, mg/kg (contaminant body burden) / mg/kg (applied daily dose)
	Inhalation of fugitive dust	$ADD_{ip} = [IR_I \times EC_{par}) / BW] \times \theta \times \psi$	ADD_{iv} = applied daily dose from inhalation of volatilized contaminants, mg/kg
		$C_{ip} = ADD_{ip} \times (\alpha_p / k_e)$	EC_{par} = concentration of particulate-bound contaminant in air, mg/ m^3
			C_{iv} = contaminant body burden in receptor from particulate inhalation, mg/kg
			α_p = particulate inhalation absorption factor, mg/kg (contaminant body burden) / mg/kg (applied daily dose)

Table 3.1 Exposure Model and Parameters (continued)

Receptors	Exposure pathway	Equations	Parameters
Terrestrial animals	Incidental Ingestion of soil or sediment	$ADD_{si} = (EC_s \times FS \times IR_f) / BW \times \theta \times \psi$	ADD_{si} = applied daily dose from incidental ingestion of soil or sediment, mg/kg, EC_s = contaminant concentration in surficial soil or sediment, mg/kg FS = mass fraction of soil or sediment in the diet, as percentage of diet on dry weight basis IR_f = food ingestion rate on dry-weight basis, kg/day
	Ingestion of water	$ADD_{wi} = EC_{dw} \times (IR_{dw} / BW) \times \theta \times \psi$	ADD_{wi} = applied daily dose from drinking water, mg/L-day EC_{dw} = average contaminant concentration at drinking water supply, mg/L IR_{dw} = ingestion rate of drinking water, mg/day
	Ingestion of food	$ADD_{fi} = \sum_{k=1}^{m} (C_k \times FR_{fk} \times IR_f/BW) \times \theta \times \psi$	ADD_{fi} = applied daily dose from ingestion of contaminated food, mg/kg m = number of food items in the diet of the receptor species C_k = contaminant concentration in the k^{th} food item, mg/kg FR_{fk} = wet weight fraction of the k^{th} food item in receptor diet, kg (food)/kg (diet)
Aquatic species	Direct contact	$C_{aq} = EC_{sw} \times BCF$	C_{aq} = contaminant body burden in aquatic receptor, mg/kg BCF = contaminant-specific bioconcentration factor, L/kg

3.2.3 Distribution Selection Criteria

Criteria have been used to select the appropriate distribution for each input parameter in a simulation. The following paragraphs will provide more details about the criteria for selecting the distribution.

Moore *et al.* (1999) used the following criteria in their work: lognormal distributions for variables with a right skewed distribution, a lower bound of zero, and no upper bound (e.g., tissue concentration); beta distributions for variables bounded by zero and one (e.g., proportion of a prey item in the diet); and, normal distributions for variables that are symmetric and not bounded by one (e.g., gross energy of prey items). Moreover, knowledge of the processes that give rise to variability can be used to select parametric distributions for fitting to data sets. The processes, which give rise to normal distribution, are suggested by the Central Limit Theorem. Also, the processes involving addition of a large number of random variables, none of which contribute significantly to the sum, would result in a normal distribution. An example of such a process is pollutant dispersion as described by the Gaussian plume model. The lognormal distribution arises from multiplicative processes, such as the dilution of pollutant concentrations.

To perform Monte Carlo procedures, probability distributions must be specified that quantitatively express the state of knowledge about each parameter. The distributions characterize the degree of belief that the true but unknown value of a parameter lies within a specified range of values for that parameter (Warren-Hicks *et al.*, 2002).

The determination of which form of distribution function should be assigned to each parameter depends on site-specific data. Therefore, the distributions employed in this study are assembled from site- specific data; data existing in the most current

literature. These were considered to be the most up to date parameter descriptions. Therefore, the selected distribution criteria are based on the selection guideline of NCRP (1996), U.S. EPA (1998a), Warren-Hicks *et al.* (2002) and Schumacher *et al.* (2001). These criteria included;

1. The selected distribution should represent the actual site-specific uncertainty and variation in that parameter.
2. The selected distribution must represent the range of the possible values of the parameter at sites. The actual field measurements of the parameter should be used to establish the distribution.
3. The selected distribution should be consistent between sites for specific parameters. However, the parameters characterizing the distribution may change. For example, if a normal distribution is chosen for a parameter at one site, then a normal distribution should be used at all other sites. However, the mean and variance of the normal distribution can be site specific
4. The form of the distribution should reflect the magnitude, range, and interpretation of the parameter. For example, contaminant concentration cannot be a negative value; therefore, the sampling distribution should reflect the restricted range, with no chance of randomly drawing a negative value. In addition, this criterion ensures that the expected site-specific range of a parameter is covered by the selected distribution. For example, use of uniform distributions over a narrow range may be appropriate when the probability of occurrence of any parameter value is equal over the range.

These criteria ensure consistency in the interpretation of the Monte Carlo outputs between sites. It also provides a foundation for dealing with sparse data sets for specific parameters at some sites. In many cases, as few as two or three observations of the parameter are available at one site, with more data available at other sites, therefore, the site with the most data can be used to determine the form of the distribution, with the sufficient statistics calculated on a site-specific basis. In addition, a consistent interpretation of the shape and range of the Monte Carlo outputs between sites requires a consistent use of parameter-specific sampling distributions. The shape of the Monte Carlo prediction distribution is generally a function of the input distributions. The use of consistent input distribution forms allows the shape of the Monte Carlo output distributions between sites to be compared. Thus, each distribution was tailored to reflect the specifics of a given site with the underlying assumptions about the nature of the distribution consistent between sites.

Therefore, the criteria above will be used to select the distribution for each parameter. The parameter characterization is cited as a guideline to understand a parameter's behavior. More details will be discussed in Chapter 5: model parameterization.

3.2.4 Selecting an Iteration Size for Monte Carlo Simulations

In Monte Carlo simulation, a value is drawn at random from the distribution for each input. The entire process is repeated m times producing m independent values with corresponding output values. These m output values constitute a random iteration from the probability distribution.

The approach to select the iteration size is based upon developing a confidence interval for a fractile level of most concern in the investigation (Morgan and Henrion, 1998). This analysis can be done for any distribution. For example, we may wish to obtain a given confidence that the value of the p^{th} fractile will be bounded by the i^{th} and k^{th} fractiles. In a Monte Carlo simulation, we can use the following relations to estimate the required iteration size (Cullen and Frey, 1999):

$$i = mp - c\sqrt{mp(1-p)} \tag{1}$$

$$k = mp + c\sqrt{mp(1-p)} \tag{2}$$

The relation in equations 1 and 2 yield a confidence interval for the p^{th} fractile if the iteration size is known, where c is the standard deviation of the standard normal distribution associated with the confidence level of interest (Cullen and Frey, 1999). To calculate the number of iterations required, the expressions above can be rearranged to calculate the confidence interval $(Y_{p-\Delta p}, Y_{p+\Delta p})$ as follows:

$$m = p(1-p)\left(\frac{c}{\Delta p}\right)^2 \tag{3}$$

For example, the 95th percentile will be enclosed by the values of the 93th and 97th fractiles, where c would be 2.0, p would be 0.95, Δp would be 0.02, and m is 475. Some of results based on the above equation are shown in Table 3.2. The m values from equation 3 agree with Brush's work. Brush (1988) reported the minimum iteration sizes for various values of Δp and the confidence levels of 80%, 90%, 95% and 99%.

Table 3.2 Number of Simulations (m) for 95th Percentile Based on Δp Values

Δp	Number of iteration (m)
0.05	76
0.025	304
0.02	475
0.015	845
0.01	1,900
0.005	7,600

For an example, 95th percentile based on Δp values (0.02), Bush reported the minimum iteration size (m) of 480, which is very close to m value, 475, from Table 3.2.

The Monte Carlo simulation is use to assess how the parameter varies statistically from input variables. Iteration sizes of 30, 50, 100, 500, 1000, 1500, 2000, 3000, 5000, 10000, 20000, 30000 were selected. The iteration size of 30 represents the small iteration size (McBean and Rovers, 1998), where the iteration sizes of 50 to 2000 represent the confidence interval based on the Δp value in Table 3.2.

Iteration sizes of 1000 to 30000 represent large sets. As an example, a random number is drawn from the standard normal distribution with a mean of 0 and standard deviation of 1; the resulting mean and standard deviation of the output distribution were then calculated. Results are shown in Table 3.3.

Table 3.3 Comparison of Mean and Standard Deviation for *m* Iterations of a Standard Normal Distribution with Mean of 0 and Standard Deviation of 1

Iteration (m)	Mean	Standard deviation
30	0.012	1.223
50	-0.015	0.915
100	0.010	0.885
500	-0.009	1.037
1000	-0.006	1.006
1500	-0.012	0.991
2000	0.019	0.997
3000	-0.008	1.012
5000	-0.018	1.011
10000	0.005	1.010
20000	-0.010	0.995
30000	-0.001	1.002

Figure 3.1 shows the distributions depending on the iteration sizes. Figure 3.2 shows the fluctuations between the random values and the iteration sizes. From Figure 3.3, all of the means of the random values based on the iteration sizes are falling in between – 0.02 and + 0.02. For standard deviation (Figure 3.3b), the values trend to stable or convergent statistics when the iteration size (m) is 500 and higher. The results were in agreement with Tellinghusen (2000) and Havens *et al.* (2002) work regarding the straight-line linear relationship between the variance and the iteration size (m^{-1}) in Figures 3.2c and the standard error ($\sigma/m^{0.5}$, where σ is a standard deviation) and the iteration size ($1/m^{0.5}$) in Figure 3.3d.

The iteration size corresponds to the number of repetitions used in the Monte Carlo simulation. The selection of iteration size is constrained by the limitation of computer hardware and time (Cullen and Frey, 1999). As iteration size is increased, computer runtime and memory use may become excessive. Therefore, it may be important to use no more iterations than are actually needed for a particular application. In an ERA model, the selected iteration size is based on the 95th confidence level. Based on Brush (1988), Cullen and Frey (1999), Havens *et al.* (2002) and the study above, the iteration size of 500 is deemed sufficient to characterize the uncertainty for models. However, the results of ERA modeling also need to represent the statistical data such as the value of variance, skewness, etc. along with the histograms.

Therefore, in applying the Monte Carlo simulation, the iteration size of 1000 is selected based on the results presented above. Other work using this iteration size includes: Duffy and Schaffner (2002); Lahkim *et al.*(1999); Sanga *et al.* (2001); Cullen

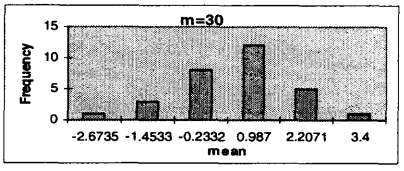


Figure 3.1a

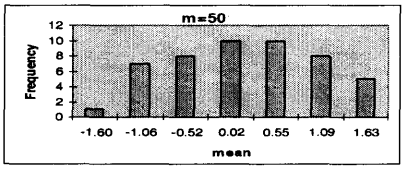


Figure 3.1b

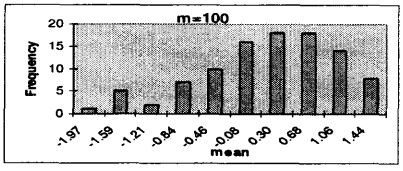
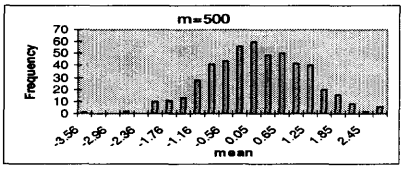


Figure 3.1c



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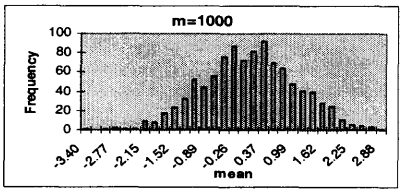

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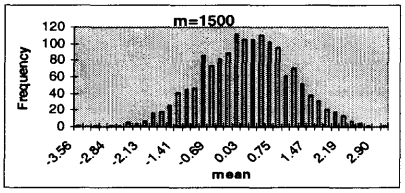


Figure 3.1f

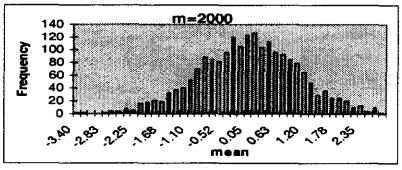
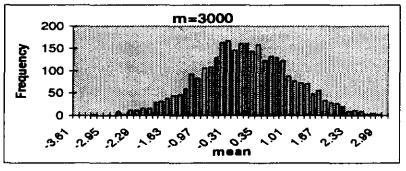


Figure 3.1g



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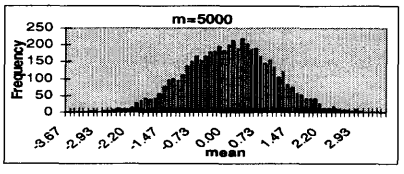


Figure 3.1i

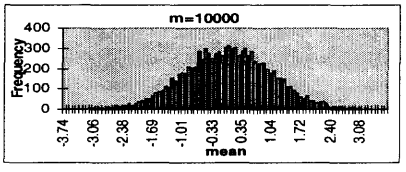


Figure 3.1j

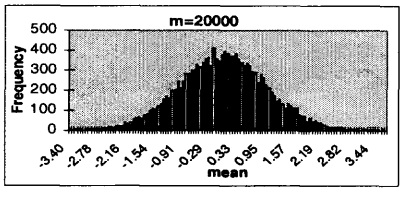


Figure 3.1k

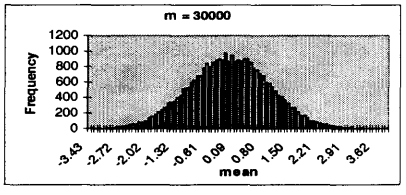


Figure 3.1l

Figure 3.1 Distributions and the Iteration Numbers.

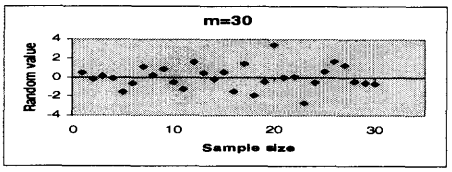
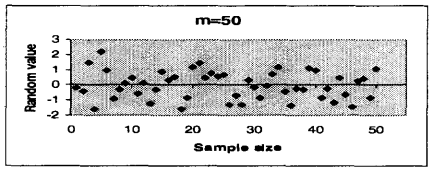


Figure 3.2a



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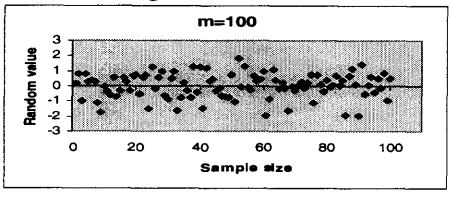

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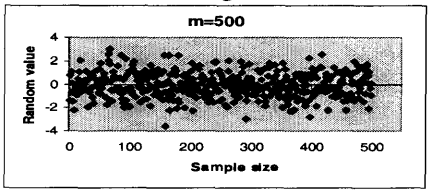
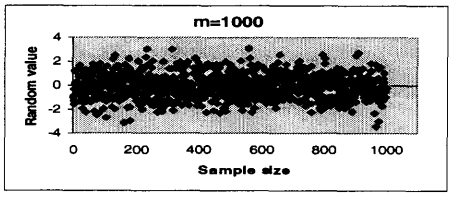


Figure 3.2d



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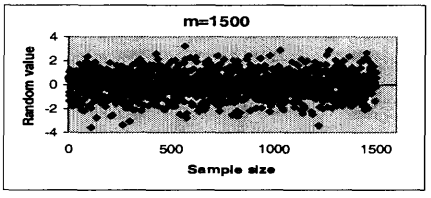

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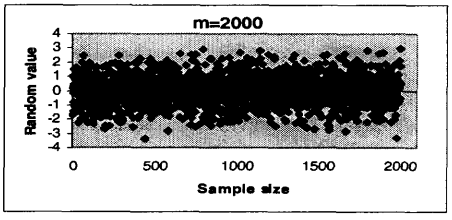

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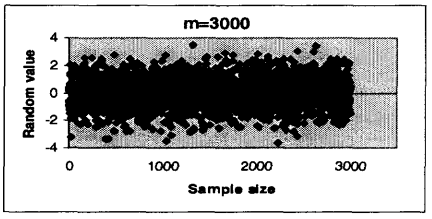

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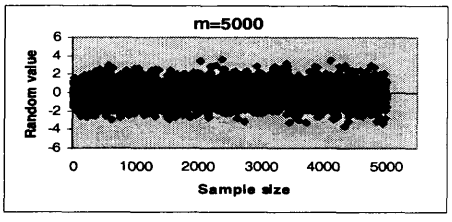
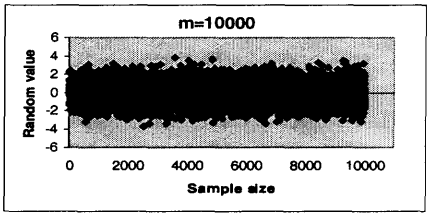


Figure 3.2i



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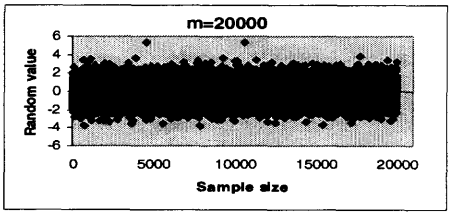


Figure 3.2k

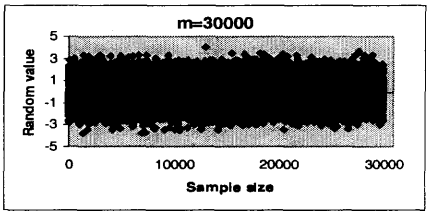


Figure 3.2l

Figure 3.2 Random Values and the Iteration Numbers.

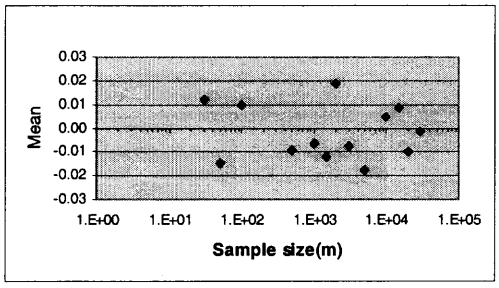


Figure 3.3a

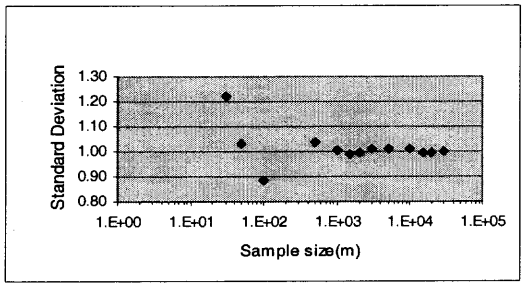


Figure 3.3b

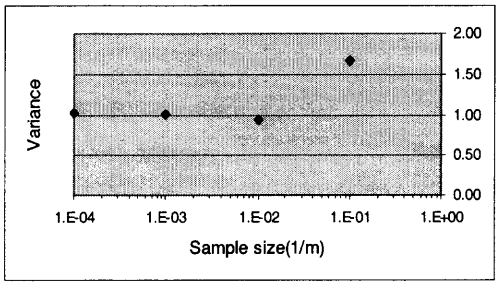


Figure 3.3c

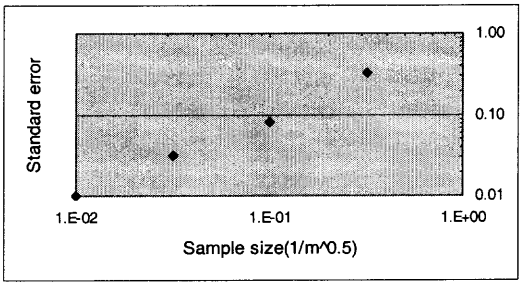


Figure 3.3d

Figure 3.3 Effect of Iteration Numbers on Convergence.

and Frey (1999); Frey and Rhodes (1998); Frey and Burmaster (1999); Schumacher *et al.* (2001); Tellinghusen (2000) and Linville *et al.* (2001).

3.2.5 Input Concentration Uncertainty

The distribution of pollutant concentrations measured in the environment often appears "lognormal"(Ott, 1990; U.S. EPA, 1997c). Using the lognormal distribution has been proposed for ambient air quality data, outdoor particulate matter exposure (Riley *et al.*, 2002), indoor radon measurements (NCRP, 1999), water quality data (Engle *et al.*, 2001: LoPez-Pila and Szewzyk, 2000), polycyclic musk fragrance in surface water (Schwartz *et al.*, 2000), exposure point concentrations in groundwater (U.S. EPA, 1991), phosphorus in lakes, dissolved solids in groundwater (Ott, 1990), radionuclides in soil, hydraulic conductivity and trace metals in human tissue, blood and feces (Wong and Yeh, 2002).

Concentration of pollutants tends to be a lognormal distribution, which has been explained by the theory of successive random dilutions (Ott, 1990; 1995). After the pollutants are emitted by the source, in the transport process before they reach the receptor, they undergo successive mixing and diluting, resulting in a lognormal frequency distribution. Ott explained this hypothesis by performing the contaminant dilution experiment. In his study, he used a random number generator to simulate 1000 repeated pouring of a beaker, which contained an initial contaminant concentration. The resulting frequency distribution is similar to the right-skewed distributions commonly observed in the environment. This study showed that a relatively simple physical process of diluting could give rise naturally to distributions that are approximately lognormal under successive dilutions.

Lu (2002) confirmed Ott's work by studying the concentrations of air pollutants in the Taiwan area. In this study, the data from three air-monitoring stations were chosen for measuring the particulate matter (PM10) frequency distribution and estimating the distribution parameters. The period of these data ranged from 1995 to 2000. The distributions were estimated by the method of moments and maximum likelihood. Comparing the results of three estimated distributions and the measured data of the particulate matters (PM10) concentration from three stations, it is apparent that the lognormal distribution fits the measured data.

According to NIOSH (1977), air pollution environmental data are described by a lognormal distribution with the following reasons: the concentrations cover a wide range of values, often several orders of magnitude; the concentrations lie close to a physical limit (zero concentration); the variation of the measured concentration is of the order of the size of the measured concentration. Therefore, NIOSH used a lognormal distribution to describe the manner of the daily contaminant exposure averages (8 hour) in the workplace.

Schorp and Leyden (2002) reported that lognormal distribution fits for Nicotine concentration in the air based on the following criteria: (1) the variable may increase without limit but cannot fall below zero; (2) the variable is positively skewed with most of the values near the lower limit; and (3) the natural logarithm of the variable yields a normal distribution. Schorp and Leyden summarized that a lognormal distribution provides a reasonable means to predict a distribution of airborne nicotine concentrations in hospitality facilities (restaurants, taverns, bars, coffee houses, etc.) and to compare distributions between geographic regions.

Cullen (2002) also studied air quality by measuring and predicting PCB concentrations in New Bedford Harbor, Massachusetts. In his study, there were multiple sources of variability and uncertainty to be considered. A set of measured values for concentration of a chemical in air is assumed to represent random draws from an underlying lognormal distribution since the dilution processes generate the concentration in the air.

MacLeod et *al.* (2002) applied a lognormal distribution to propagate uncertainty of PCB concentrations in both soil and water at Lake Ontario in chemical fate and bioaccumulation. The results showed that the relationships between uncertainty in input and output parameters are linear based on log plots, which suggested that a lognormal distribution is an appropriate fit to the data set. Vermeire *et al.* (2001) applied the lognormal distribution to the following parameters: dibutylphthalate (DBP) contaminant concentrations in air, surface water, soil, groundwater and fish (bio-concentration factor) in Europe. The results showed that the distribution of the total human dose of DBP, as derived from the distribution inputs, trend is lognormal.

To demonstrate that a lognormal distribution is appropriate for contaminant concentrations in the environment, the three data sets of New Jersey water quality monitoring during 1995 to 2001 from USGS database will be used (U.S. Geological Survey, 2002). The monitoring locations are Passaic River at Millington, at Two Bridges, and at Little Falls. Dissolve Sulfate (SO_4) will represent the contaminant concentration in this study. The data set is shown in Table 3.4.

To determine whether the lognormal distribution is an adequate descriptor of the data set, the Shapiro-Wilk statistical goodness of fit test is used as a test method.

Table 3.4 Dissolved Sulfate (SO_4) Concentrations from the Rivers in New Jersey (USGS, 2002)

Location	Passaic River at Two Bridges		Passaic River at Little Falls		Passaic River at Millington	
No. of Samples	Date	SO4, mg/L	Date	SO4, mg/L	Date	SO4,mg/L
1	Aug-96	45	Jan-95	17	Jan-95	19
2	Aug-96	47	Feb-95	29	Mar-95	15
3	Sep-96	53	Mar-95	18	May-95	10
4	Sep-96	34	Apr-95	31	Jun-95	9.6
5	Sep-96	31	May-95	31	Oct-95	51
6	Oct-96	28	May-95	29	Jan-96	29
7	Oct-96	13	Jun-95	31	Mar-96	17
8	Nov-96	19	Jun-95	41	May-96	11
9	Dec-96	13	Jul-95	18	Jul-96	8.6
10	Jan-97	22	Aug-95	38	Oct-96	12
11	Jan-97	24	Sep-95	54	Jan-97	22
12	Feb-97	25	Sep-95	30	Mar-97	15
13	Mar-97	15	Oct-95	28	May-97	13.8
14	Apr-97	14	Nov-95	20	Jun-97	13.7

Table 3. 4 Dissolved Sulfate (SO_4) Concentrations from the Rivers in New Jersey (continued) (USGS, 2002)

Location	Passaic River at Two Bridges		Passaic River at Little Falls		Passaic River at Millington	
No. of Samples	Date	SO4,mg/L	Date	SO4, mg/L	Date	SO4,mg/L
15	Apr-97	21.7	Jan-96	32	Jul-97	54.6
16	May-97	21.4	Feb-96	18	Jul-98	15.4
17	May-97	21.2	Mar-96	18		
18	Jun-97	30.4	Apr-96	17		
19	Jul-97	22.7	May-96	15		
20	Jul-97	26.6	Jun-96	19		
21	Aug-97	33.4	Jun-96	28		
22	Sep-97	47.6	Jul-96	12		
23	Oct-97	52.1	Aug-96	32		
24	Nov-97	16.3	Sep-96	41		
25	Nov-97	34.3	Sep-96	24		
26	Nov-97	35.8	Nov-97	29.5		
27	Dec-97	38.3	Mar-98	18.3		
28	Jan-98	20.8	May-98	14.8		
29	Jan-98	26	Sep-98	34.1		

Table 3.4 Dissolved Sulfate (SO_4) Concentrations from the Rivers in New Jersey (continued) (USGS, 2002)

Location	Passaic River at Two Bridges		Passaic River at Little Falls	
No. of Samples	Date	SO4,mg/L	Date	SO4,mg/L
30	Feb-98	20	Nov-98	42.3
31	Feb-98	15.4	Feb-99	29.9
32	Mar-98	14.3	May-99	30
33	Apr-98	15.4	Aug-99	30.7
34	May-98	11.2	Nov-99	20.1
35	May-98	12	Feb-00	17.4
36	Jun-98	13.5	May-00	19.7
37	Aug-98	39.2	Aug-00	20.6
38	Nov-98	58.2	Nov-00	53
39	Jan-99	23	Feb-01	20.1
40	May-99	31.9	May-01	33.2
41	Aug-99	54	Sep-01	49.4
42	Sep-99	11		
43	Nov-99	40		
44	Feb-00	17.4		
45	May-00	27.3		
46	Aug-00	24.6		
47	Nov-00	32.4		
48	Feb-01	22.3		
49	May-01	29.1		
50	Aug-01	34.8		

The Shapiro-Wilk test is a statistical goodness of fit test that performs well on small sample sizes and tests the null hypothesis that the data values are random samples from a normal distribution against an unspecified alternative distribution (McBean and Rovers, 1998). The test is considered one of the best numerical tests of normality and is particularly useful for detecting departures from normality in the tails of a sample distribution. It can be used in conjunction with a probability plot to measure how well the plotted quintiles are following a straight line (i.e., how well the sample values are correlated with normal quintiles.

The Shapiro-Wilk test is used to test the normality of the data (U.S. EPA, 1997c). In this EPA report, the author illustrated which distributions are fit to data set. The higher value of *W*-test, the more fit of that distribution Results indicate the lognormal distribution provides a reasonable fit to the data. Kumagai *et al.* (1997) examined either lognormality or normality of the data sets of cobalt exposure concentrations by using the Shapiro Wilk *W* test.

The Shapiro-Wilk, *W* test values resulted in half of the data sets being rejected by normality, but log-normality could not be rejected because the W value based on the hypothesis of log-normality was larger than that of normality, so that the distribution was closer to lognormal. Davis *et al.* (2001) examined which distribution fits to arsenic contamination in soil of 50 samples from nine sites in California, USA. The distribution analysis, using the Shapiro-Wilk goodness of fit test, indicated that the arsenic data best fit a lognormal distribution.

To determine the distribution of sensitivities to toxic stress among an within field populations of *Dapnia* magna, Barata *et al.* (2002) used a Shapiro-Wilk test as a tool to

test whether the range of sensitivities within populations was normally distributed or not. Clonal effect concentration (EC) values obtained within each of the studied population and toxicant were tested by Shapiro-Wilk tests. The results from their study showed that the clonal sensitivities followed a lognormal distribution. The steps in the calculation are:

1. Order the sample data
2. Compute a weighted sum (b) of the differences between the most extreme observations.
3. Divide the weighted sum by a multiple of the standard deviation, and square the result to get the Shapiro-Wilk statistic *W*:

$$W = \left\{ \frac{b}{S\sqrt{n-1}} \right\}^2 \tag{4}$$

where the numerator is computed as

$$b = \sum_{i=1}^{k} a_{n-1+1}\left(x_{n-i+1} - x_{(i)}\right) = \sum_{i=1}^{k} b_i \tag{5}$$

where $x_{(i)}$ represents the smallest ordered value in the sample, and coefficient a_i depend on the sample size n. The coefficients can be found for any sample size from 3 to 50 in Appendix B. The value of k can be found as the greatest integer less than or equal to n/2.

Normality of the data should be rejected if the Shapiro-Wilk statistic is too low when compared to the critical values. The *W*-critical values are dependent on the sample sizes. For example, at the significance level of 0.01, the critical values are 0.8 and 0.9 for the sample size of 22 and 35, respectively (McBean and Rovers, 1998).

For significance level, traditionally, scientists have used either the 0.05 level or the 0.01. The lower the significance level, the more the data must diverge from the null

hypothesis to be significant. The advantage of using 0.01 levels is that it is less likely to make a Type 1 error; a true null hypothesis can be incorrectly rejected. The other words, in a Type I error, the conclusion is drawn that the null hypothesis is false when; in fact, it is true (Vining, 1998). On the other hand, increasing significance level (e.g., from 0.01 to 0.05 or 0.10), increases the chances of making a Type I Error. Therefore, in this study, the significance level of 0.01 will be used for a critical value.

The data from Table 3.4 were used to calculate the *W* values based on the above procedure with results shown in Table 3.5. From the results, the estimated *W* values of the lognormal distribution function are greater than the critical *W* values. On the other hand, the estimated W values of the normal distributions are lower than the critical *W* values. This indicates that the lognormal distribution is fit to describe the character of contaminants in the environment. Moreover, when plotting the histogram of data sets between the normal distribution function and the lognormal distribution function, the histograms of normal distribution function show a right-skewed trend, and the histograms of the lognormal distribution function show a bell curve trend (Figures 3.4 -3.6). These results reveal that logarithms of the contaminant concentration data are approximately normally distributed (Peretz *et al.*, 1997; NIOSH, 1977). As discussed above, the lognormal distribution describes random variables resulting from multiplicative environmental processes. Also, the concentration of a contaminant in the environment is often well described by a lognormal distribution because it results from dilution processes in water or air (Ott, 1990: 1995; Klein, 1997; Cullen and Frey, 1999; Vermeire et *al.*, 2001; Lu, 2002; Cullen, 2002; Schorp and Leyden, 2002).

Table 3.5 Shapiro Wilk, *W* Test Results

Location	Shapiro Wilk, *W* Test[a]		
	Normal fit	**Lognormal fit**	**Critical Value[b]**
Passaic River at Millington	0.002	0.88	0.84
Passaic River at Little Falls	0.91	0.95	0.92
Passaic River at Two Bridges	0.922	0.96	0.93

[a]: reject the null hypothesis if an estimated value is lower than a critical value (Gilbert, 1987)

[b]: critical value at significance level of 0.01

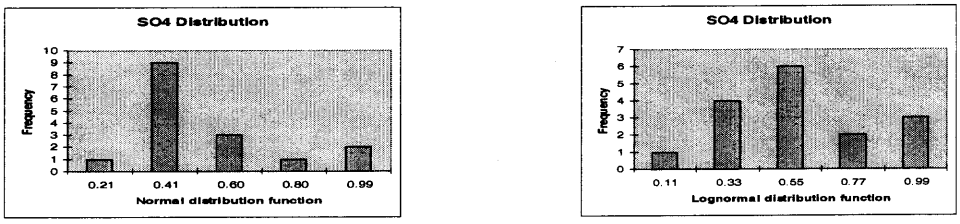


Figure 3.4 The Dissolved Sulfate Concentration Distributions at Passaic river, Millington,
NJ (1995-1998).

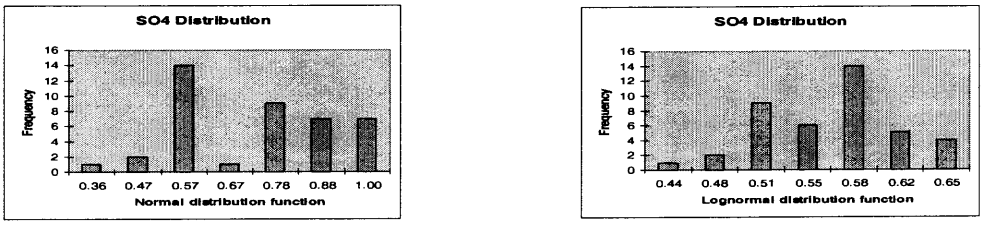


Figure 3.5 The Dissolved Sulfate Concentration Distributions at Passaic River, Little Falls, NJ (1995-2001).

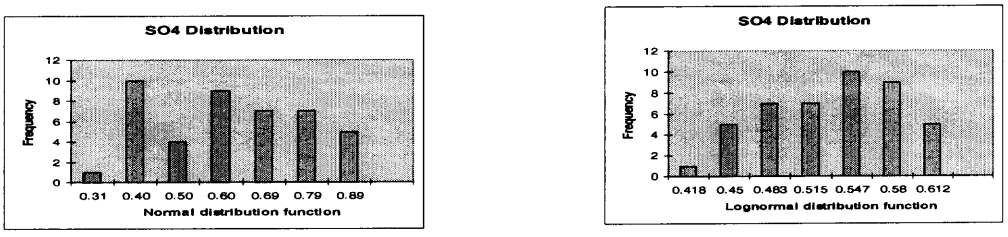


Figure 3.6 The Dissolved Sulfate Concentration Distributions at Passaic River, Two Bridges, NJ (1996-2001).

Other reasons include that, in the environment, negative contaminant concentrations are not plausible and the lognormal distribution precludes values less than zero, and the distribution has no upper bound (McBean and Rovers, 1998). Due to these reasons, the lognormal distribution has considerable potential to describe contaminant concentrations in water, soil, and air.

3.3 Demonstration

Receptors and contaminants selected to demonstrate both sensitivity and uncertainty analysis in these models are from Yuma Proving and Aberdeen Proving Grounds. The receptors in both sites are listed in Table 3.6, and include:

- Terrestrial animal and plant exposure
- Aquatic animal and plant exposure

3.4 The Area of Study

Aberdeen Proving Ground (APG) and Yuma Proving Ground (YPG) are selected sites for this study as they are the default ones within the ERA (Lu, 2001) software. Aberdeen Proving Ground provides large areas of natural habitat for many species (Lu, 2001). The post is composed of roughly 50% hardwood forest, 34% mowed/grassy areas, 13% marsh or marsh shrub, 2% bare earth, and 1% shrub habitat. Forested regions represent a transition zone between the oak-pine and oak-chestnut regions of the eastern U.S. APG also contains large areas of wetland, which provide habitat for plant species such as the slender blue flag, an endangered marsh plant. APG study area map is shown in Figure 3.7.

Table 3.6 Receptors of Aberdeen Proving Ground & Yuma Proving Ground (Lu, 2001)

	Aberdeen Proving Ground	Amount	Yuma Proving Ground	Amount
	Receptors		**Receptors**	
Birds	Mallard, American kestrel, barred owl, bald eagle	4	Mexican spotted owl, Loggerhead shrike, gamble's quail	3
Mammals	White-tailed deer, beaver, white-footed mouse, cottontail rabbit, Indiana bat	5	Kit fox, cactus mouse, black-tailed jackrabbit, mule-deer, lesser long-nosed bat	5
Reptiles & Amphibians	Eastern garter snake, lizards, woodhouse's toad	4	Desert tortoises, sonoran whipsnake, desert spiny lizard	3
Aquatic Animals	Mayfly, mussels, clams, carp, rainbow	5		
Aquatic Plants	Water millfoil, phytoplankton, periphyton	3		
Terrestrial Plants	fern, rushes, slender blue flag	3	Creosote bush, foothill paloverde trees, saguaro cactus	3

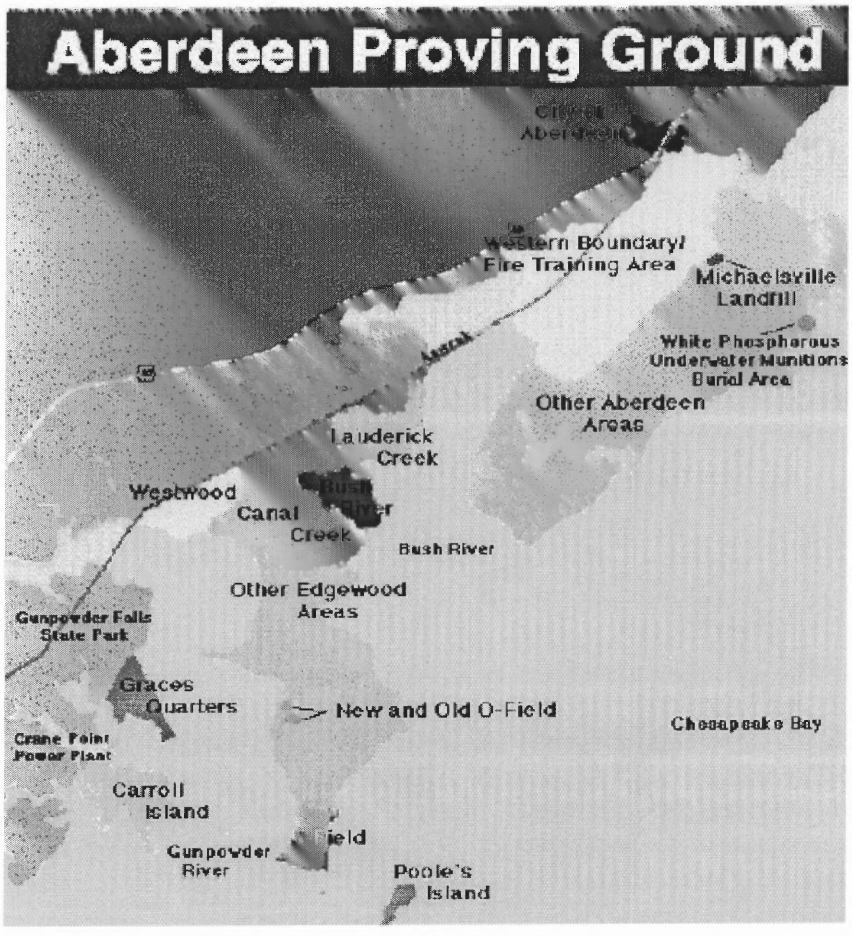


Figure 3.7 Map of APG Study Areas (U.S. Army APG, 1998).

YPG is characterized by a terrestrial ecosystem, which consists of desert plants, wildlife, and habitats (U.S. Army YPG, 1999). There are also many typical desert animals living around the proving ground. The most common types of wildlife include game mammals (such as bighorn sheep and mule deer), desert birds, predatory and fur-bearing mammals, and migratory and resident birds. Predatory and fur-bearing mammals include the coyote, kit fox, gray fox, ringtail, badger, spotted skunk, striped skunk, mountain lion, and bobcat (Lu, 2001). YPG study area map is shown in Figure 3.8.

Considering the large area of YPG and the great diversity of the APG ecosystem, a large amount of wildlife species lives within the two sites. One hundred and fourteen species at APG and 30 species at YPG were identified for the study areas. Based on the appropriate criteria for screening the study area species (PNNL, 1998; U.S. EPA, 1998a) that include commercial or recreational importance and status under the Endangered Species Act, the number of receptors is reduced to 24 for APG and 14 for YPG (Lu, 2001). The shortlist of representative receptors is shown in Table 3.6.

The effect of the food chain/food web imbedded in the ERA software DBMS for these receptors will be addressed as part of parameter input and model uncertainty.

3.5 Contaminants of Interest

Initial screening and validation will be accomplished with a comparative risk analysis of chromium (VI), depleted uranium (DU), tantalum, and molybdenum. These contaminants were selected because both tantalum and molybdenum are alternative coatings to replace chromium. Depleted uranium is included because both Aberdeen and Yuma Proving ground sites are contaminated by depleted uranium as both sites are a center for Army material testing, laboratory research, and military training.

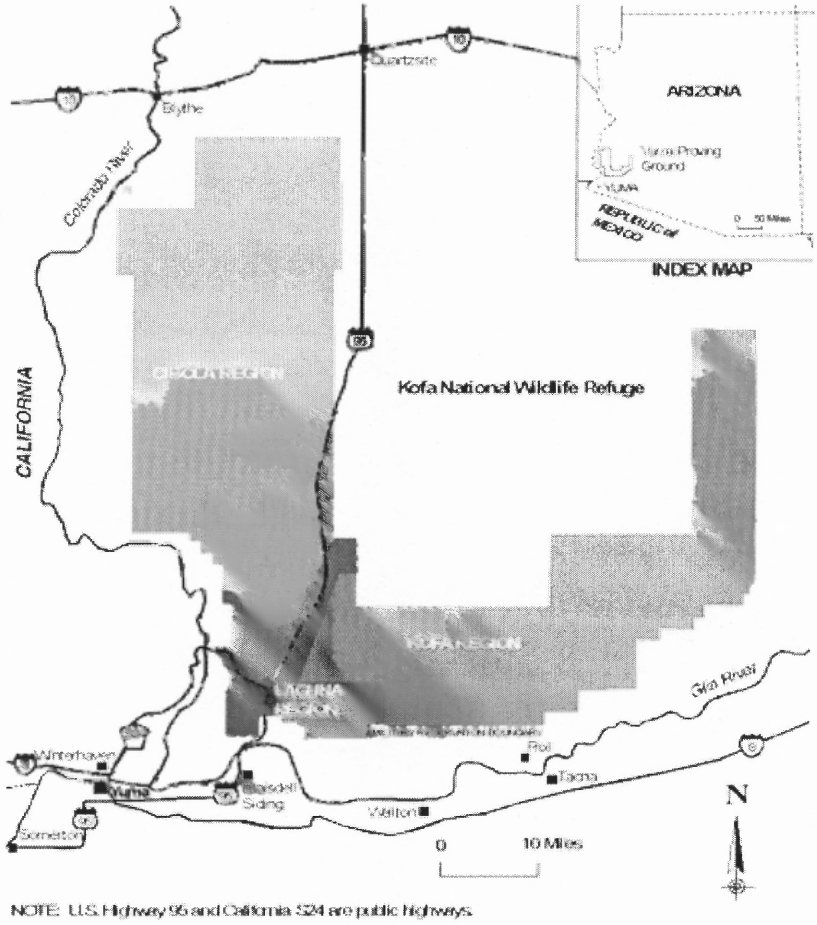


Figure 3.8 Map of YPG Study Areas (U.S. Army YPG, 1999).

CHAPTER 4

ERA MODEL CODE MODIFICATION

One of the objectives of this dissertation is to develop computationally efficient methods for uncertainty propagation. This objective includes: each methods computational requirements, applicability of the methods to a wide range of models and the user friendliness of the methods.

ERA2001 software was developed as a tool to implement an ecological risk assessment to evaluate the impact of different chemicals on an ecosystem. It is part of the Department of Defense "Sustainable Green Manufacturing" program. The developed software consists of a dynamic exposure model and a DBMS. The exposure model was developed based on the algorithms for evaluating different contaminant exposure pathways (Lu, 2001). Microsoft Access was selected to construct the local database and store all the related parameters, which will be used to run the exposure model. Based on the specific case requirements, these stored data can be modified through a Windows interface developed with Visual Basic 6.0. Using this software, one can implement a comprehensive ecological risk assessment considering each exposure pathways with the data provided by the local database (Lu, 2001).

The software (ERA2001 BetVersion1.2) includes a Windows based interface, mathematical model, and a local database. To implement an Ecological Risk Assessment case study, the user selects the appropriate chemicals and receptors involved, inputs the chemical concentrations, runs the exposure model and analyzes the results. The user also

can review the data stored in the database and insert his or her own data if it is not yet included. The model is also linked to external databases, such as the U.S. EPA ECOTOX (U.S. EPA, 2003). Therefore, if the user cannot find the required data in the local database, external databases can be used to locate the data and apply them in the model.

As shown in Figure 4.1, the ERA2001 software package consists of three levels: user, databases, and application program. The user sends commands through the VB interface. Data are retrieved from the local Microsoft Access database. The retrieved information will be applied to the mathematical model and the final results are calculated.

However, the current ERA model version does not include parameter and model uncertainty analysis. Thus the model software needs to be modified. Probabilistic distributions through Monte Carlo simulations will be applied to analyze uncertainty in this model. The Monte Carlo simulation generates random numbers based on the selected distribution. The additional codes for this task will be written using Visual Basic. Both parameter and model uncertainty will be reported in terms of the frequency and the cumulative distribution functions and their statistical data. A Microsoft Excel spreadsheet will be used to maintain and present the results in the Visual Basic program. The details will discuss in the following section.

4.1 ERA Model Code Modification Procedures

Modules for the application of probabilistic distribution- derived from Monte Carlo simulation methods were developed as a part of this work. The Monte Carlo method involves the following steps:

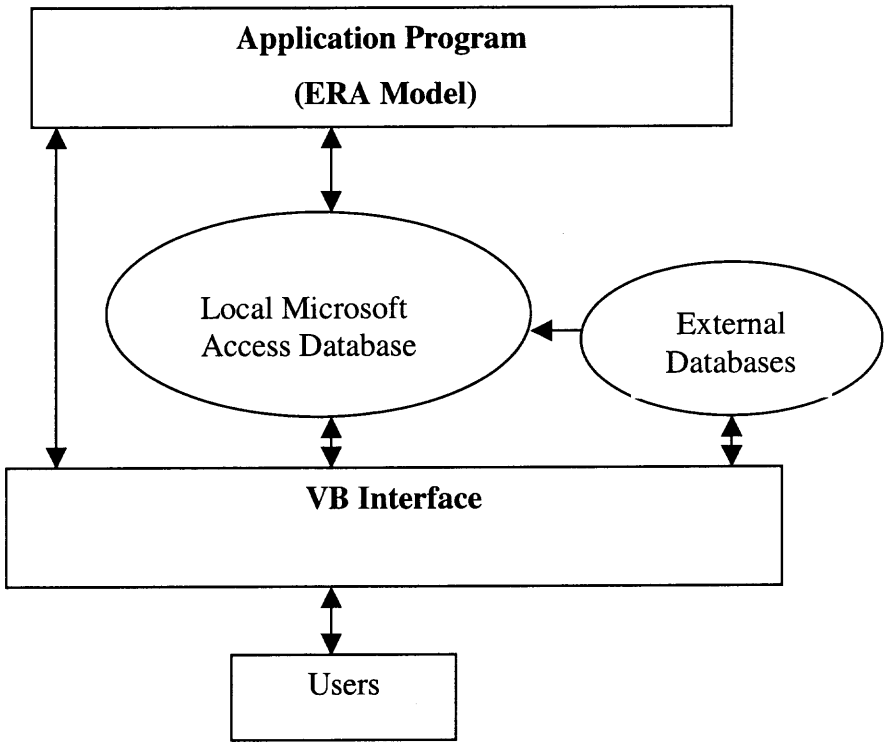


Figure 4.1 System Organization (Lu, 2001).

(1) Obtaining random samples from the probability distributions of the inputs,

(2) Performing model simulations for the combination of the sampled inputs, and

(3) Statistically analyzing the model outputs.

The random numbers for sampling the input distributions were generated depending on the parameter considered. VB interfaces were modified to accept the uncertain parameter inputs from both input interfaces and a local database. Model simulations were performed at the sampled values of the inputs. The outputs of the simulations were analyzed by using the data analysis function from the Microsoft Excel menu. These include descriptive statistic data, frequency and cumulative probability density functions. Therefore, the user can easily save the final result under their file names. The approach in this task involves the use of simulation and Monte Carlo methods. These methods are used to provide distributions on estimated risks. The method for assessing parameter and model uncertainty involves the following steps:

(1) Select a distribution to describe the parameter.

(2) Use Monte Carlo sampling to produce a distribution

(3) Calculate the exposure value

(4) Store the exposure value

(5) Generate the frequency and cumulative distribution functions of each exposure (dependent on pathway)

(6) Generate the statistical data to present the uncertainty

Visual basic codes were written based on the above procedures. To better understand the structure of the model see Figures 4.2 to 4.5, which present the model organization concepts. Also, Figure 4.6 presents the Monte Carlo simulation framework. Appendix C shows the modified ERA model and the format of that model. As a result, users will find the ERA software friendlier than the previous software version.

4.2 Summary

From the approach, the codes were modified to develop a computationally efficient method for uncertainty propagation. The Monte Carlo Sampling method is applicable to a wide range of ecological risk assessment models associated with uncertainty propagation as already discussed in Chapter 2. In the past, a computational model may not be feasible due to computer capability and time limitations. Nowadays, the capacity of computers can overcome these limitations. The ease in which a method can be used is an important factor in model applicability. The use of Visual Basic offers an alternative technique to develop a user-friendly probabilistic simulation tool. Microsoft Excel is also useful and easily used to calculate the descriptive statistics and probabilistic distributions.

A set of interface tools was built to integrate Monte Carlo sampling and analysis techniques with the ERA model. The software was written in Visual Basic and supplemented with Microsoft Excel, which allows the user to store the outputs from multiple-run modeling sets. Since much of the functionality of Microsoft Excel is available in Excel's Visual Basic for Applications (VBA) programming environment, VBA scripts were developed to set up and manage the Monte Carlo analysis. Figures C-1 to C-14 in Appendix C show the general flow of the interface system.

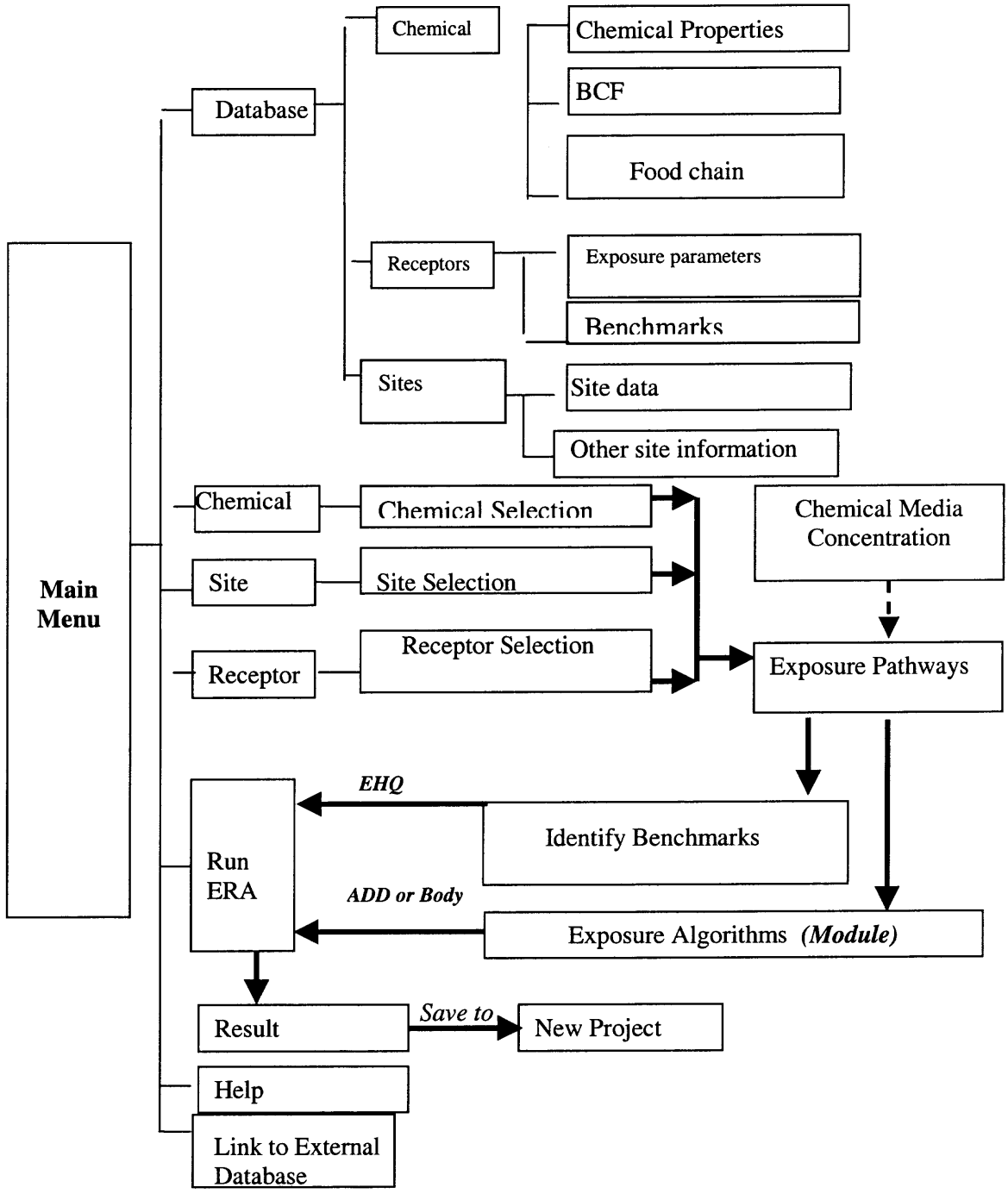


Figure 4.2 Current ERA2003 Software Architecture (Lu, 2001).

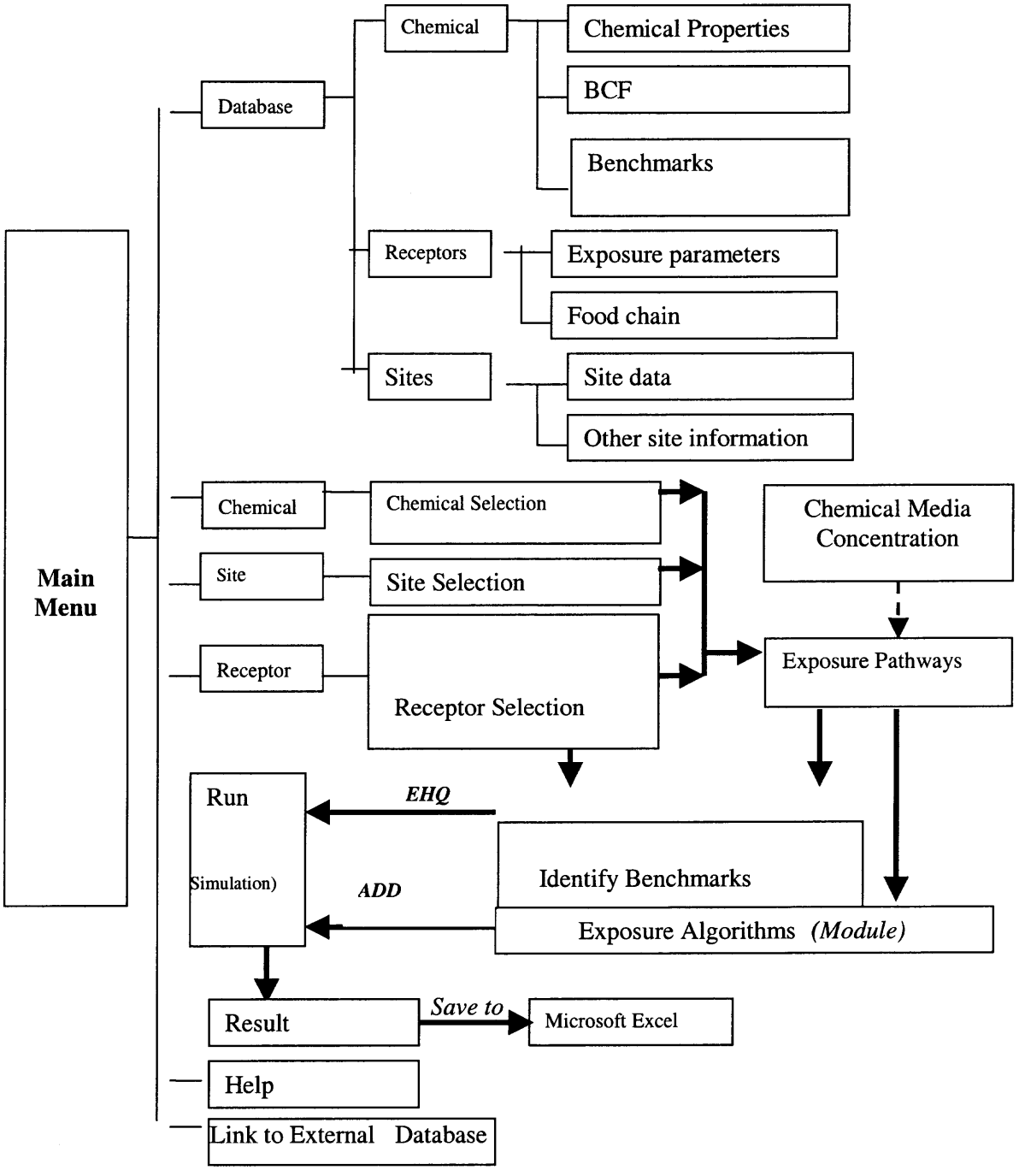


Figure 4.3 Modified ERA2003 Software Architecture.

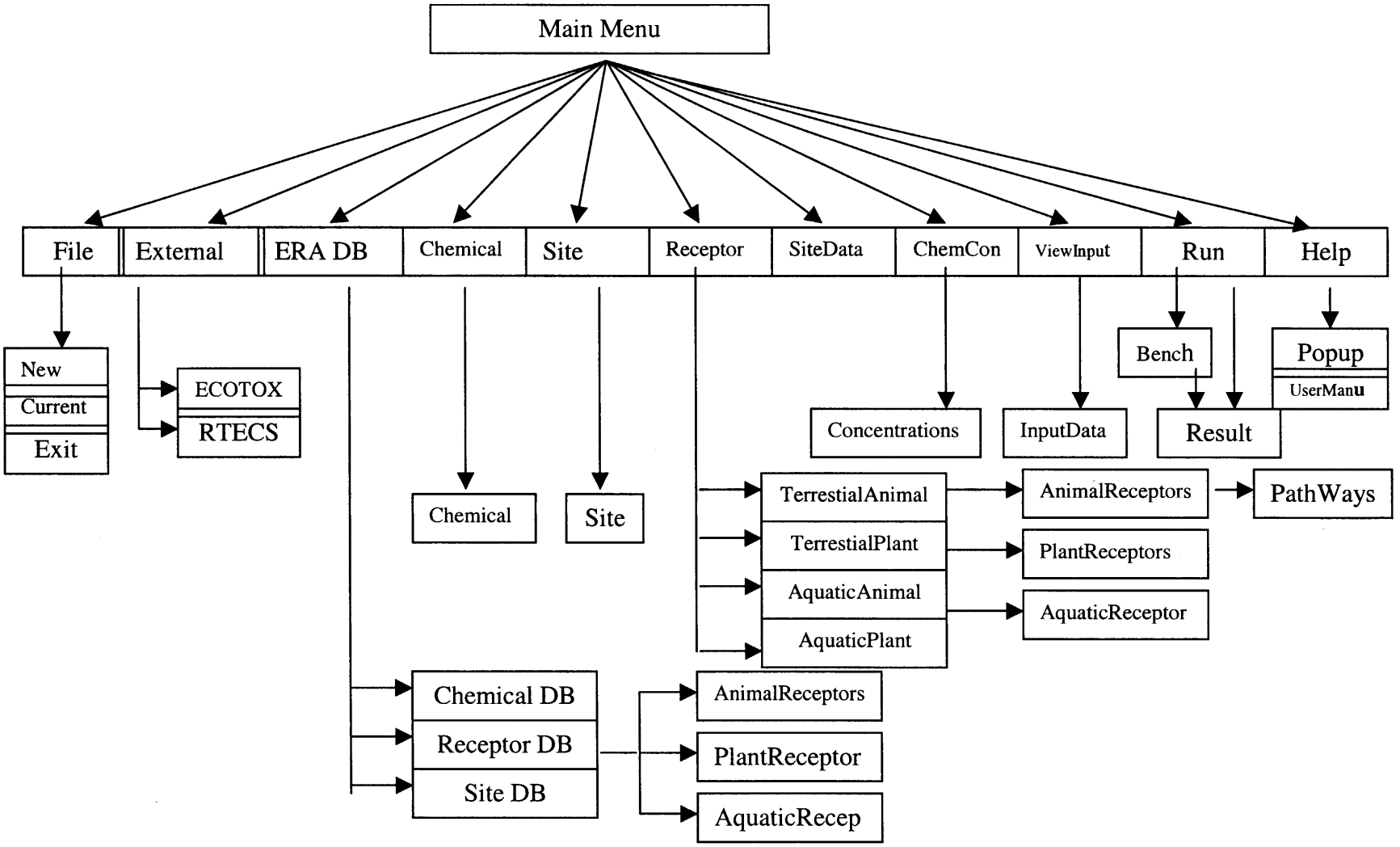


Figure 4.4 Current ERA2003 Software Interface Flowchart (Lu, 2001).

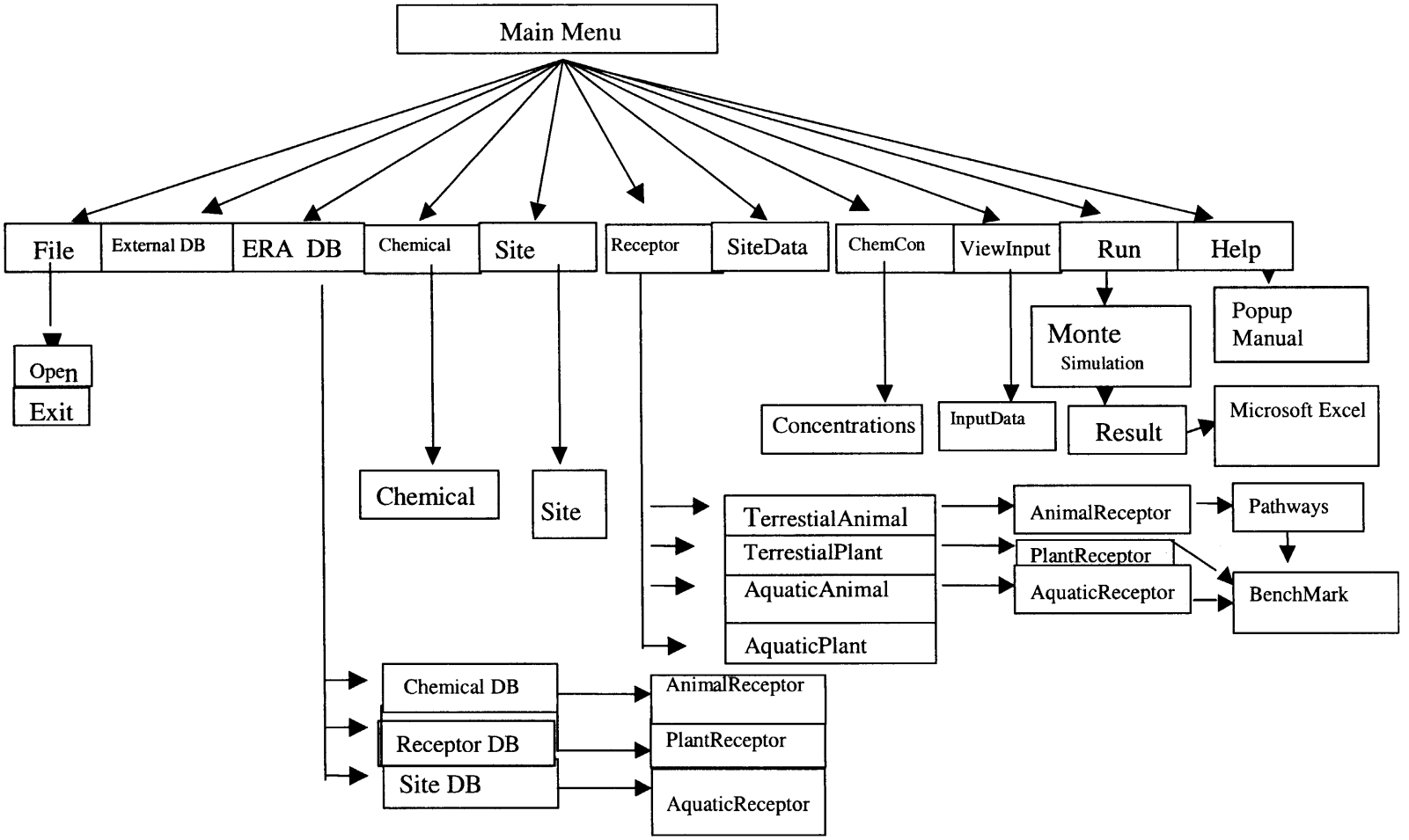


Figure 4.5 Modified ERA2003 Software Interface Flowchart

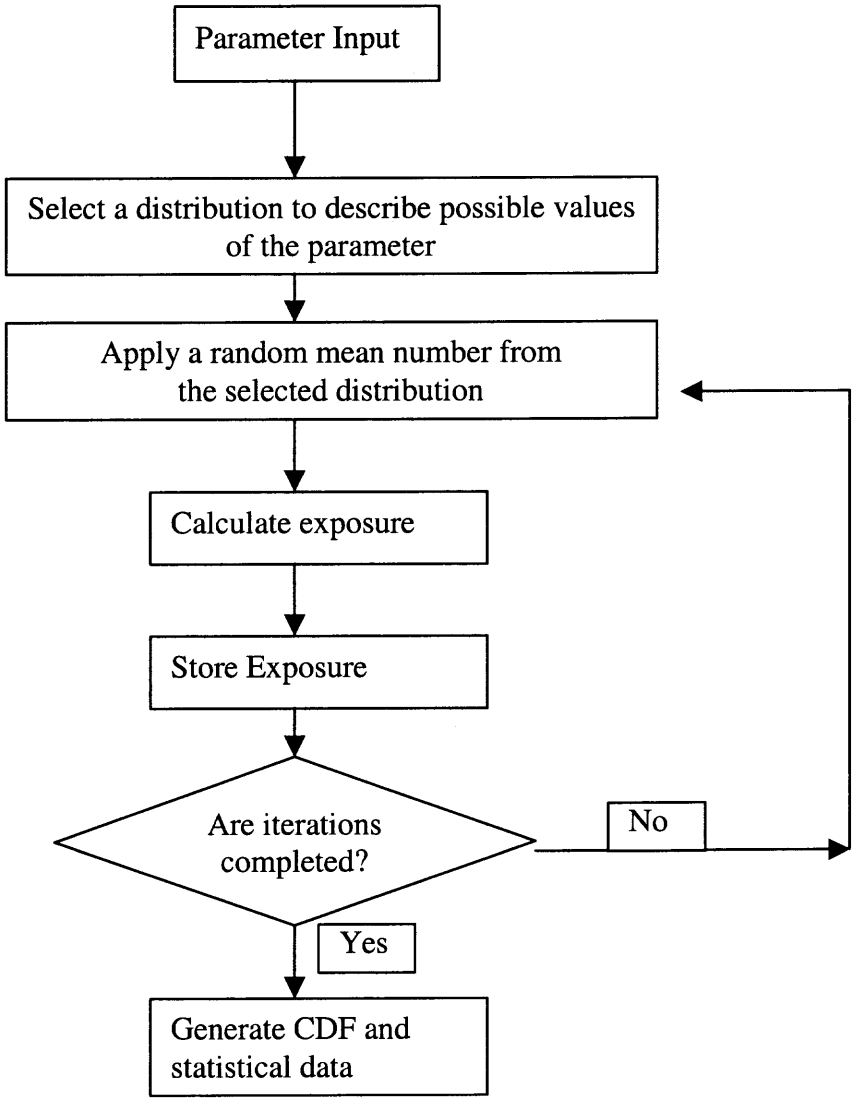


Figure 4.6 Monte Carlo Simulation Procedures.

To perform a simulation, the user first must select the inputs by following the guidelines spelled out step by step in the interface. The appropriate distribution to describe each receptor's behavior is already assigned in the VB codes. When a set of runs is initiated via the VBA codes, the Monte Carlo routine generates samples from the distributions to set the input values for the current simulation. The existing input files are then saved in the same directory as the local database. The results are imported into Microsoft Excel.

As discussed earlier in the previous Chapter, selecting an appropriate distribution to describe the parameter is the critical step. The next Chapter will discuss how to approach and select the distribution based on the characteristic and the behavior of that parameter at the specific site.

CHAPTER 5

MODEL PARAMETERIZATION

The following sections discuss parameter characteristics used in the ERA model. Each parameter has been studied with respect to specific receptors and contaminants. Receptors include terrestrial and aquatic plants and animals. Contaminants include both organic and inorganic compounds. Data have been gathered from a range of sources. The study focuses on parameter characterization and parameter behavior. The first section presents the parameters of terrestrial animal species; the second, default values; the third, parameters of aquatic and plant species; the fourth, contaminant concentrations; and the fifth, a summary.

5.1 Animal Species

Parameters of terrestrial animal species include the body weight, mass fraction of soil or sediment in the diet, food and water ingestion rate, inhalation rate, soil-to-skin adherence factor, surface area, weight fraction of food item in receptor diet, fraction of receptor surface area in contact with soil per day, site use factor, contaminant-specific dermal absorption factor, and seasonal factor. Details for each parameter are discussed in the following sections.

5.1.1 Body Weight (BW)

Table 5.1 contains the mean, minimum, maximum, range, minimum and maximum values as percents of the mean, and standard deviation of receptor body weights for the

Table 5.1 Body Weight

Receptor	Body weight (kg)						
	Mean	Min.	MAX.	Range	Min. value as a % of Mean	Max. value as a % of Mean	SD*
Mammal							
Beaver[5]	19.50	11.00	30.00	19.00	56	154	4.75
Black tailed jackrabbit[1]	2.30	1.80	3.60	1.80	78	157	0.45
Cactus mouse[7]	0.22	0.20	0.43	0.23	90	195	0.06
Cottontail rabbit[5]	1.24	0.70	1.80	1.10	56	145	0.28
Indiana bat[7]	0.01	0.01	0.02	0.01	80	200	0.00
Kit fox[3]	2.06	1.50	3.00	1.50	73	146	0.38
Lesser long nosed bat[5]	0.01	0.01	0.02	0.01	100	200	0.00
Mule deer[1]	74.00	70.00	150.00	80.00	95	203	20.00
White tailed deer[5]	80.00	18.00	136.00	118.00	23	170	29.50
White-footed mouse[7]	0.02	0.02	0.05	0.04	68	227	0.01
Bird							
American kestrel[2]	0.13	0.10	0.14	0.04	81	109	0.01
Bald eagle[2]	5.09	4.36	5.76	1.40	86	113	0.35
Barred owl[4]	0.76	0.47	1.06	0.59	62	140	0.15
Gamble's quail[3]	0.17	0.10	0.21	0.10	62	125	0.03
Loggerhead shrike[3]	0.05	0.04	0.05	0.01	85	115	0.00
Mallard[4]	0.47	0.36	0.57	0.21	77	123	0.05
Mexican spotted owl[4]	0.64	0.52	0.76	0.24	81	119	0.06
Reptiles & Amphibians							
Desert spiny lizard[8,9]	0.03	0.02	0.04	0.02	67	133	0.01
Desert tortoise[1,10,11]	0.40	0.35	0.45	0.10	88	111	0.02
Eastern garter snake[12]	6.00	4.50	7.30	2.80	75	122	0.70
Lizards[8,9]	0.03	0.02	0.04	0.02	67	133	0.01
Sonora whipsnake[1,12]	0.11	0.02	0.25	0.23	18	227	0.06
Woodhouse's toad[13]	0.05	0.03	0.07	0.04	60	140	0.01

* Standard deviation (SD) is calculated by using the equation (10)

Sources:

1) U.S DOE, 1997
2) U.S EPA, 1993a
3) U.S. Army YPG, 1998
4) Dunning, 1993
5) Macdonald, 1984
6) Chapman and Feldhamer, 1982
7) Walker, 1968
8) U.S. Fish and Wildlife Service, 2001
9) Bradshaw, 1986
10) Ernest *et al.*, 1994
11) Pope, 1939
12) Ditmars, 1939
13) Feder and Burggren, 1992

YPG and APG sites (U.S. DOE, 1997; U.S. EPA, 1993a; U.S. Army YPG, 1998; Dunning, 1993; Macdonald, 1984; Chapman and Feldhamer, 1982; Walker, 1968).

Since full data was unavailable, the standard deviation was calculated by using the range of values method (Ponce, 1980). The results show that the range of body weight for each receptor varied considerably. This variation is expected when considering normal body weight variation in the growth process for a particular species.

Mammals showed the greatest range of variation particularly among the larger animals such as mule deer and white tailed deer. The extreme cases showed some animals with as little as 23% of the mean body weight and some with over twice the mean body weight. Smaller animals showed similar variation relative to their smaller mean values.

The most significant weight variation among birds was with the Bald Eagle, which had a mean body weight over five times that of other birds. All the bird species fell between 62% and 125% of their mean values with the exception of Barred Owls, which had samples as large as 140% of the mean.

Reptiles and Amphibians also showed considerable variation averaging from as low as 60% of the mean to as high as 140%. A notable exception was the Sonora whipsnake, which ranged from 18% to 227% of it's mean. The large mean body weight of the Eastern garter snake resulted in its significantly high standard deviation (0.70 kg) when compared to other reptiles and amphibians (0.01 to 0 .06 kg).

Approach: Body weight data must be obtained individually for each receptor. Physiological parameters such as body weight in terrestrial animals may vary seasonally,

geographically, and by age. This parameter typically follows a Gaussian distribution (Regan *et al.*, 2002; U.S.EPA, 1993a; 1999b).

The normal distribution is commonly used to represent uncertainty resulting from unbiased measurement errors (Morgan and Henrion, 1998). Because the normally distributed random variable takes on values over the entire range of real data, we have provided the standard deviation as the measure of population variance. The normal distribution describes the behavior of body weight (Cullen and Frey, 1999; Hope, 1999). The propagation error for this parameter can be demonstrated in terms of a standard deviation value. The normal probabilistic distribution formula is

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\{-\frac{(x-\mu)^2}{2\sigma^2}\}, for -\infty \le x \le \infty \tag{6}$$

where μ is the mean and σ is the standard deviation of the random variable x

The mean is calculated by using the following equation (Vining, 1998):

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{7}$$

The standard deviation is calculated by using the following formula (Vining, 1998):

$$\sigma = \sqrt{\frac{n\sum_{i=1}^{n} x_1^2 - \left(\sum_{i=1}^{n} x_1\right)^2}{n(n-1)}} \tag{8}$$

If a standard deviation (σ) is unknown, the estimation method will be used. Ponce (1980) provided the equation to estimate the variance of samples.

$$\sigma^2 = \frac{(Range)^2}{4^2} \tag{9}$$

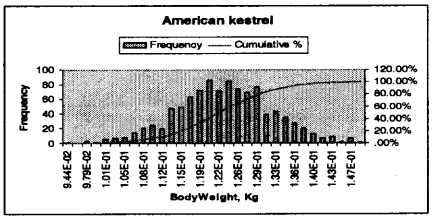
Where *Range* is from the smallest to the largest values.

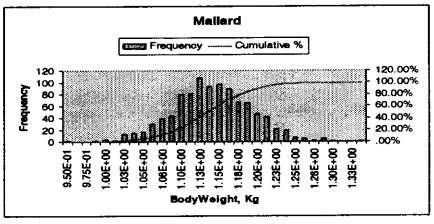
Therefore, in performing an uncertainty analysis for the receptor's body weight, at least the range of the body weight must be known. The sources of the data are shown in Table 5.1. Equation (9) will be used when the standard deviation or variance is unknown. The mean and standard deviation will be propagated into the error of the exposure model by Monte Carlo simulation method. Finally, probability distributions for terrestrial animals from both APG and YPG sites are constructed from the normal distributions for data presented as means and standard deviations. The result contains all possible distributions given the available information (Figures 5.1 and 5.2)

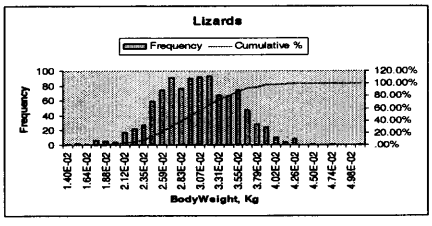
5.1.2 Ingestion and Inhalation Rates

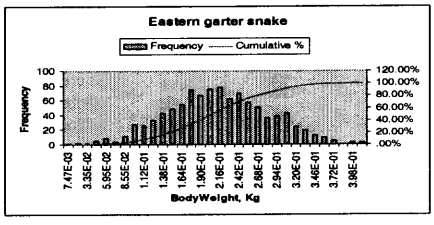
The associated equations for food and water ingestion rates and inhalation rates are show in Table 5.2. Also, Tables 5.2 to 5.5 contains the data for food and water ingestion rates and inhalation rates of mammals and birds at the APG and YPG sites (U.S. Army YPG, 1998).

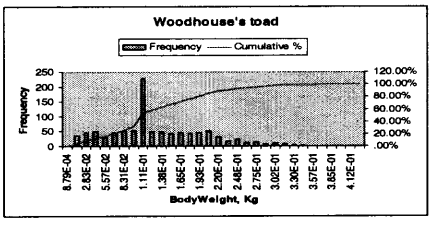
These parameters depend on the body weight of the receptor. In most cases, the variation in all three parameters falls within 10% of each other. The exceptions are all found within the water ingestion data where four mammals and one bird species exhibit range differences of up to 33%. In general, as seen in Tables 5.3 to 5.5, body weight

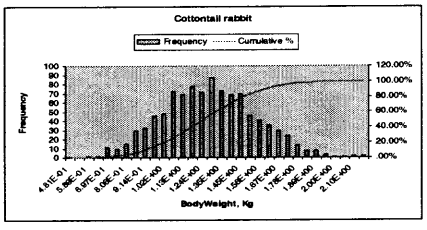


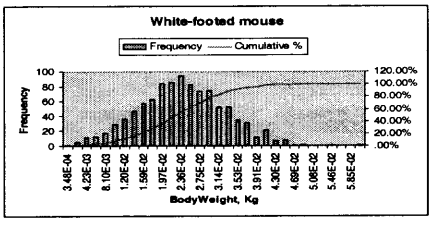


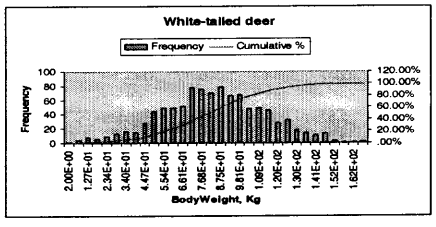


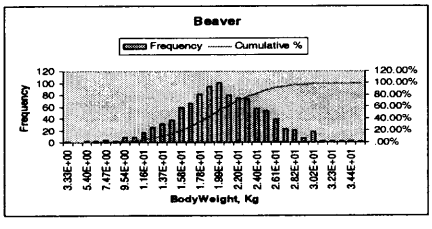


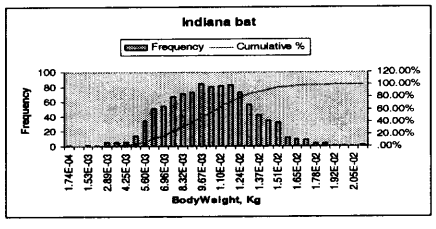


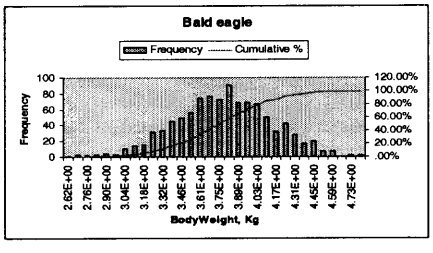












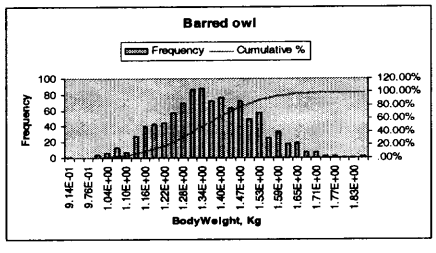
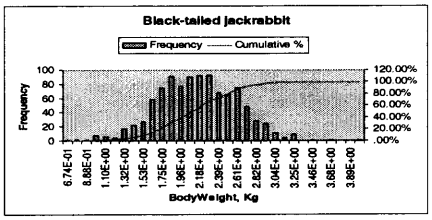
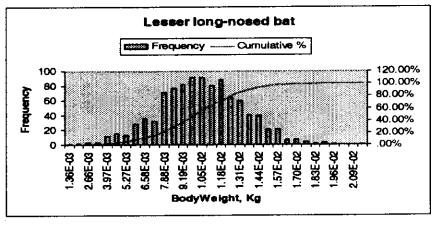
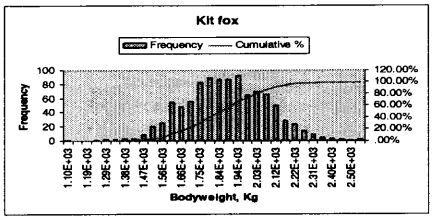
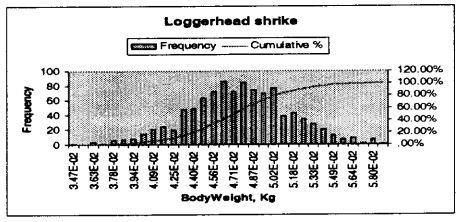


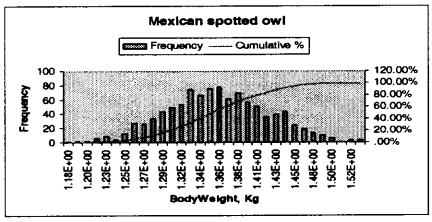
Figure 5.1 Body Weights of APG Terrestrial Animals.

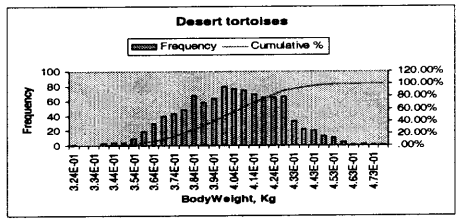


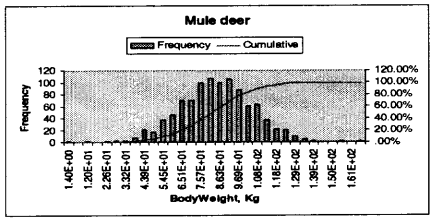


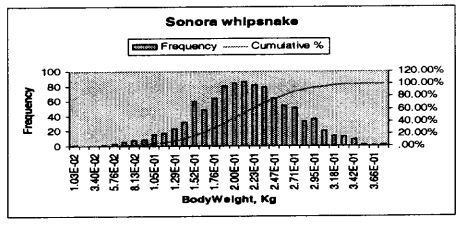


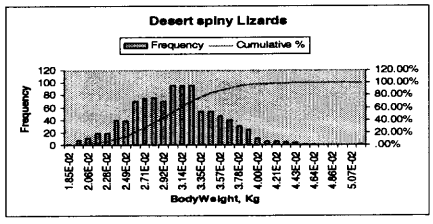


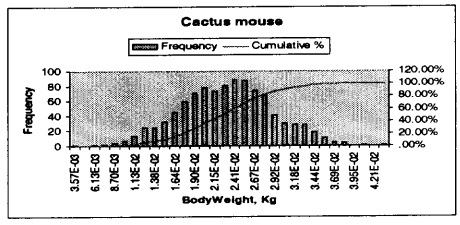












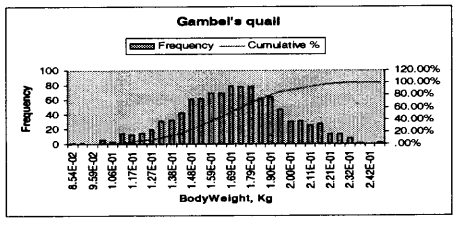


Figure 5.2 Body Weights of YPG Terrestrial Animals.

Table 5.2 Food and Water Ingestion Rate, Inhalation Rate Equations (U.S. EPA, 1993a)

Receptor	Food ingestion rate	Water ingestion rate	Inhalation rate
Mammals	$IR_f = 0.235\ BW^{0.822}$	$IR_{dw} = 0.099 \times BW^{0.90}$	$IR_i = 0.5458 \times BW^{0.80}$
Birds	$IR_f = 0.0582\ BW^{0.651}$	$IR_{dw} = 0.059 \times BW^{0.67}$	$IR_i = 0.4089 \times BW^{0.77}$
Reptiles & Amphibians	$IR_f = 0.013(BW*1000)^{0.773}$	$IR_{dw} = 0$	$IR_i = 0.00045*(BW*1000)^{0.8}$

Table 5.3 Food Ingestion Rate

Receptor	Food ingestion rate (kg/d)						
	Mean	Min.	Max.	Range	Min. value as a % of Mean	Max. value as a % of Mean	SD*
Mammal							
Beaver	2.70	1.69	3.85	2.16	62	142	0.54
Black tailed jackrabbit	0.47	0.38	0.67	0.29	82	145	0.07
Cactus mouse	0.07	0.06	0.12	0.06	91	172	0.01
Cottontail rabbit	0.28	0.18	0.38	0.21	63	136	0.05
Indiana bat	0.01	0.00	0.01	0.01	80	180	0.00
Kit fox	0.43	0.33	0.58	0.25	77	136	0.06
Lesser long nosed bat	0.01	0.01	0.01	0.00	100	180	0.00
Mule deer	8.08	7.72	14.45	6.73	96	179	1.68
White tailed deer	8.62	2.53	13.33	10.80	29	155	2.70
White-footed mouse	0.01	0.01	0.02	0.01	70	200	0.00
Bird							
American kestrel	0.02	0.01	0.02	0.00	87	107	0.00
Bald eagle	0.17	0.15	0.18	0.03	90	108	0.01
Barred owl	0.05	0.04	0.06	0.02	73	122	0.01
Gamble's quail	0.02	0.01	0.02	0.01	72	117	0.00
Loggerhead shrike	0.01	0.01	0.01	0.00	88	113	0.00
Mallard	0.04	0.03	0.04	0.01	86	114	0.00
Mexican spotted owl	0.04	0.04	0.05	0.01	88	114	0.00
Reptiles and Amphibians							
Desert spiny lizard	0.18	0.13	0.23	0.09	73	125	0.02
Desert tortoise	1.34	1.20	1.45	0.25	90	109	0.06
Eastern garter snake	0.83	0.67	2.60	3.93	80	116	0.98
Lizards	0.18	0.13	0.23	0.09	73	125	0.02
Sonora whipsnake	0.49	0.13	0.93	0.80	27	189	0.20
Woodhouse's toad	0.27	0.18	0.35	0.17	67	130	0.04

* Standard deviation (SD) is calculated by using the equation (10)

Table 5.4 Water Ingestion Rate

Receptor	Water ingestion rate (L/d)						
	Mean	Min	Max	Range	Min. value as a % of Mean	Max. value as a % of Mean	SD*
Mammal							
Beaver	1.43	0.86	2.11	1.26	60	147	0.31
Black tailed jackrabbit	0.21	0.17	0.31	0.15	80	150	0.04
Cactus mouse	0.03	0.02	0.05	0.02	92	184	0.01
Cottontail rabbit	0.12	0.07	0.17	0.10	60	140	0.02
Indiana bat	0.00	0.00	0.00	0.00	50	150	0.00
Kit fox	0.19	0.14	0.27	0.12	75	140	0.03
Lesser long nosed bat	0.00	0.00	0.00	0.00	100	150	0.00
Mule deer	4.76	4.53	9.00	4.47	95	189	1.12
White tailed deer	5.11	1.34	8.24	6.90	26	161	1.73
White-footed mouse	0.00	0.00	0.01	0.01	67	233	0.00
Birds							
American kestrel	0.02	0.01	0.02	0.00	87	107	0.00
Bald eagle	0.18	0.16	0.19	0.03	90	109	0.01
Barred owl	0.05	0.04	0.06	0.03	71	124	0.01
Gamble's quail	0.02	0.01	0.02	0.01	72	117	0.00
Loggerhead shrike	0.01	0.01	0.01	0.00	88	100	0.00
Mallard	0.04	0.03	0.04	0.01	86	114	0.00
Mexican spotted owl	0.04	0.04	0.05	0.01	86	111	0.00

* Standard deviation (SD) is calculated by using the equation (10)

Table 5.5 Inhalation Rate

Receptor	Inhalation rate (m^3 /d)						
	Mean	Min	Max	Range	Min. value as a % of Mean	Max. value as a % of Mean	SD*
Mammal							
Beaver	5.88	3.72	8.29	4.58	63	141	1.14
Black tailed jackrabbit	1.06	0.87	1.52	0.65	82	143	0.16
Cactus mouse	0.16	0.15	0.28	0.13	92	171	0.03
Cottontail rabbit	0.65	0.41	0.87	0.46	63	135	0.12
Indiana bat	0.01	0.01	0.02	0.01	79	171	0.00
Kit fox	0.97	0.76	1.31	0.56	78	135	0.14
Lesser long nosed bat	0.01	0.01	0.02	0.01	100	171	0.00
Mule deer	17.08	16.34	30.05	13.72	96	176	3.43
White tailed deer	18.18	5.51	27.79	22.28	30	153	5.57
White-footed mouse	0.03	0.02	0.05	0.03	73	192	0.01
Birds							
American kestrel	0.08	0.07	0.09	0.02	86	107	0.00
Bald eagle	1.43	1.27	1.57	0.30	89	110	0.08
Barred owl	0.33	0.23	0.43	0.20	69	129	0.05
Gamble's quail	0.10	0.07	0.12	0.05	69	118	0.01
Loggerhead shrike	0.04	0.03	0.04	0.01	87	110	0.00
Mallard	0.23	0.19	0.27	0.08	82	117	0.02
Mexican spotted owl	0.29	0.25	0.33	0.09	85	114	0.02
Reptiles and Amphibians							
Desert spiny lizard	0.01	0.01	0.01	0.00	71	129	0.00
Desert tortoise	0.05	0.05	0.06	0.01	91	109	0.00
Eastern garter snake	0.47	0.38	0.55	0.18	80	117	0.04
Lizards	0.01	0.01	0.01	0.00	71	129	0.00
Sonora whipsnake	0.02	0.01	0.04	0.03	26	195	0.01
Woodhouse's toad	0.01	0.01	0.01	0.01	70	130	0.00

*Standard deviation (SD) is calculated by using the equation (10)

and ingestion/inhalation rates are related. This relationship allows the use of a normal distribution to describe the characteristics of these parameters. The mean and the standard deviation are required to perform an uncertainty analysis.

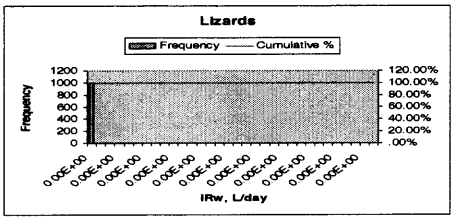
Approach: The approach to perform an uncertainty analysis for the ingestion and inhalation rates involves the same approach used in the case of the body weight parameter, because both ingestion and inhalation rates are body weight dependent. They are estimated with algometric equations and are expected to be Gaussian as well (U.S. EPA, 1993a). The Monte Carlo simulation method will be applied using the mean and the standard deviation to construct the distribution for each receptor, then randomly selecting one value to calculate the exposure. Finally, probability distributions for terrestrial animals from both the APG and YPG sites are constructed from the normal distributions for data presented as means and standard deviations. The results contain all possible distributions given the available information (Figures 5.3-5.8).

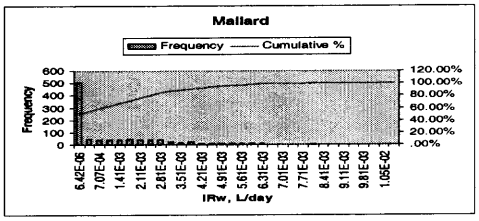
5.1.3 Surface Area

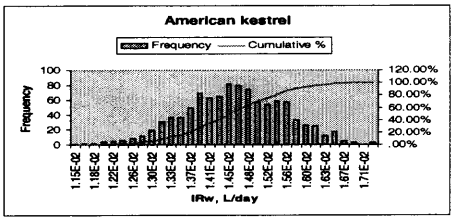
The degree to which an animal may absorb contaminants through direct contact with its skin depends on many factors, including the surface area of the skin available for contact (U.S. EPA, 1989a). The permeability of an animal's skin to contaminants depends on characteristics of the contaminant. The U.S. EPA (1993a) provides the equations for estimating skin surface area (SA):

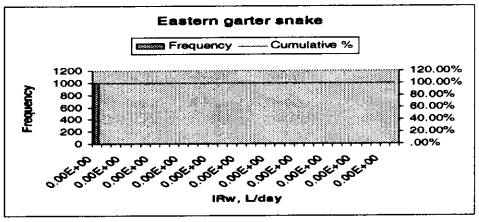
$$\text{Birds: } SA = 10 * (BW * 1000)^{0.667}$$

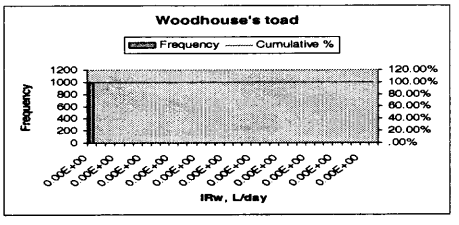
$$\text{Mammals: } SA = 12.3 * (BW \times 1000)^{0.65}$$

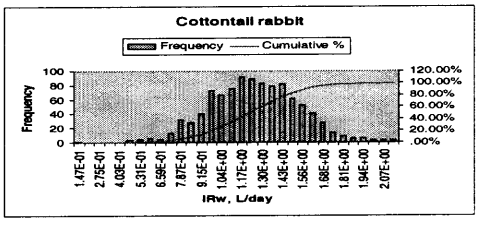


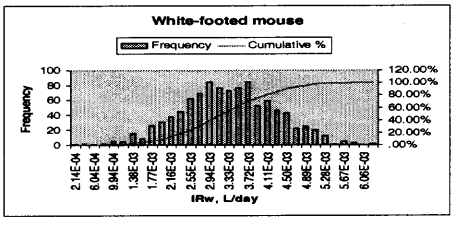


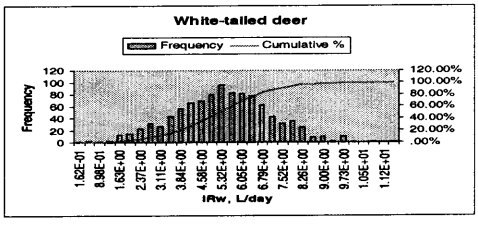


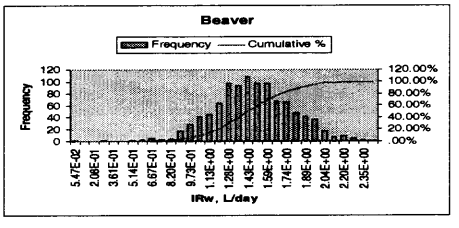


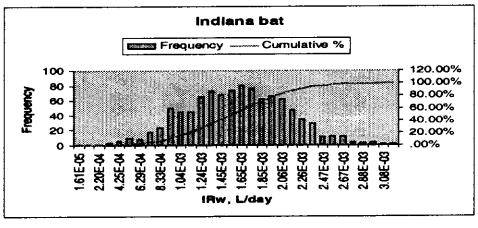


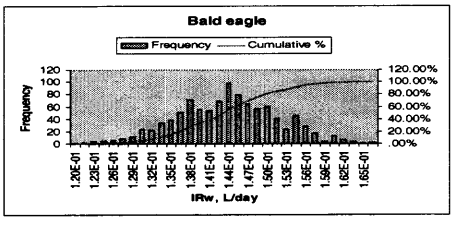












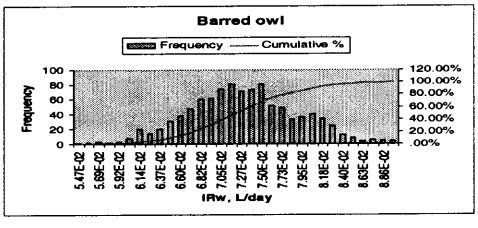


Figure 5.3 Water Ingestion Rates of APG Terrestrial Animals.

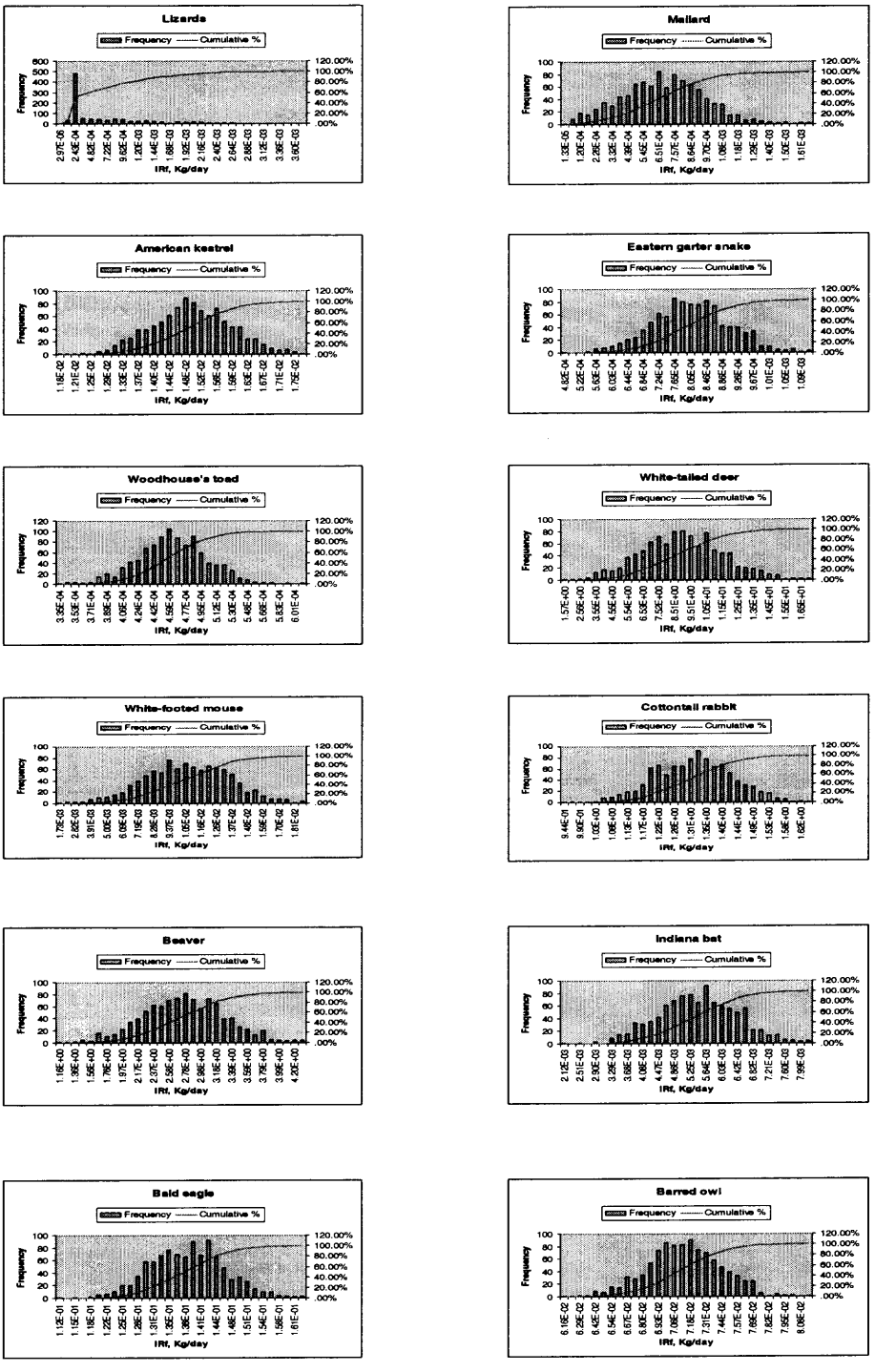
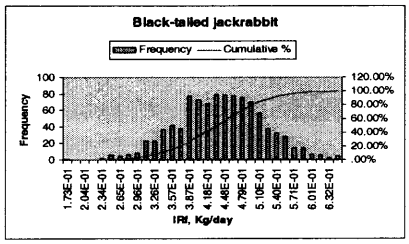
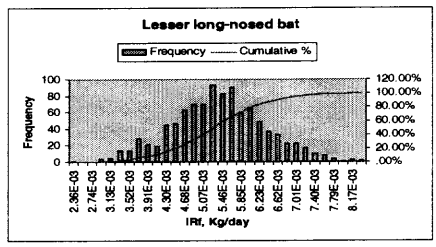
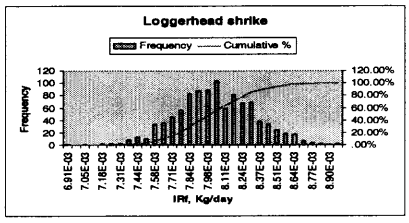
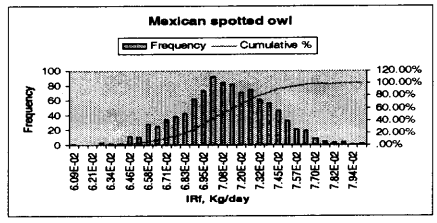


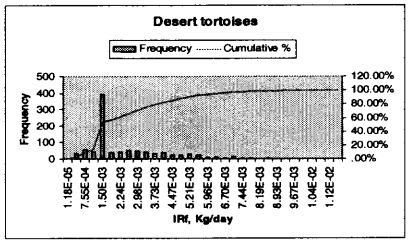
Figure 5.4 Ingestion Rates of APG Terrestrial Animals.

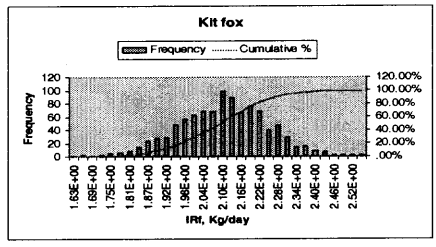


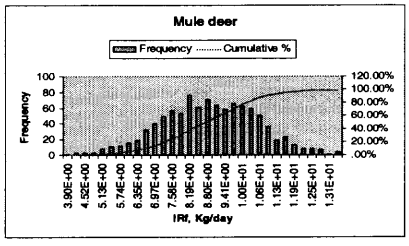


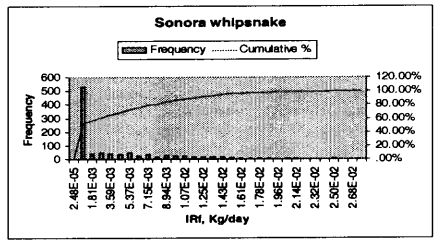


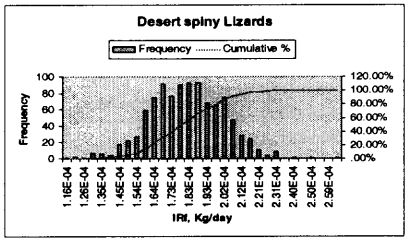


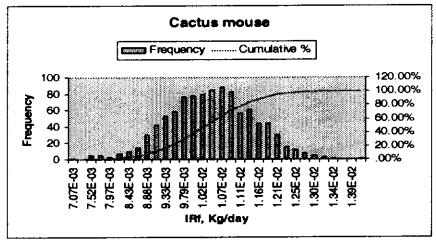












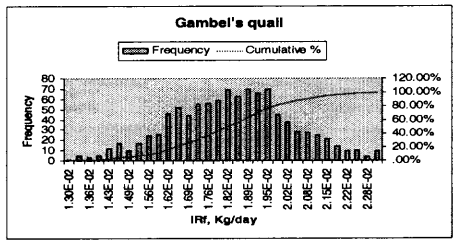
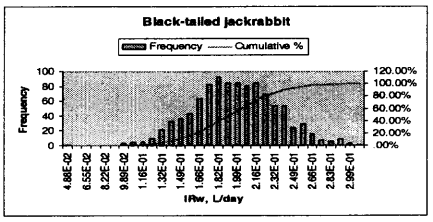
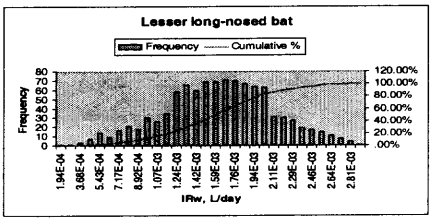
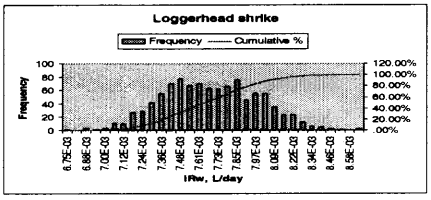
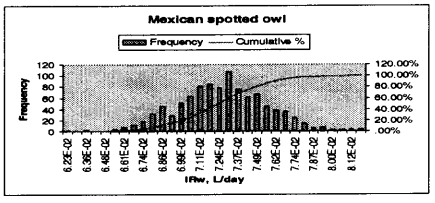


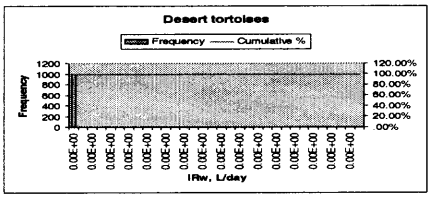
Figure 5.5 Food Ingestion Rates of YPG Terrestrial Animals.

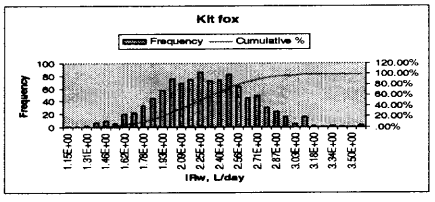


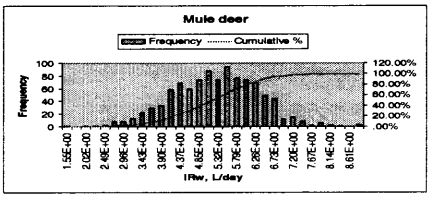


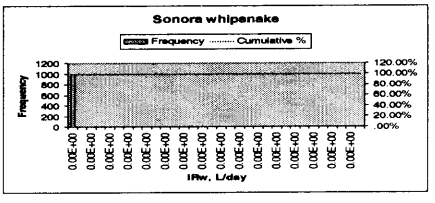


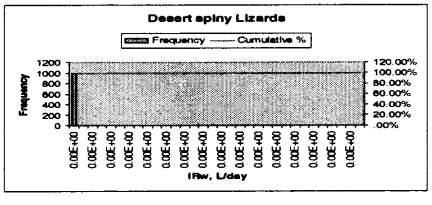


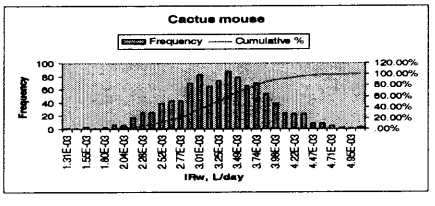












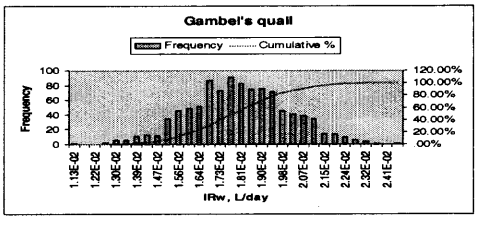


Figure 5.6 Water Ingestion Rates YPG Terrestrial Animals.

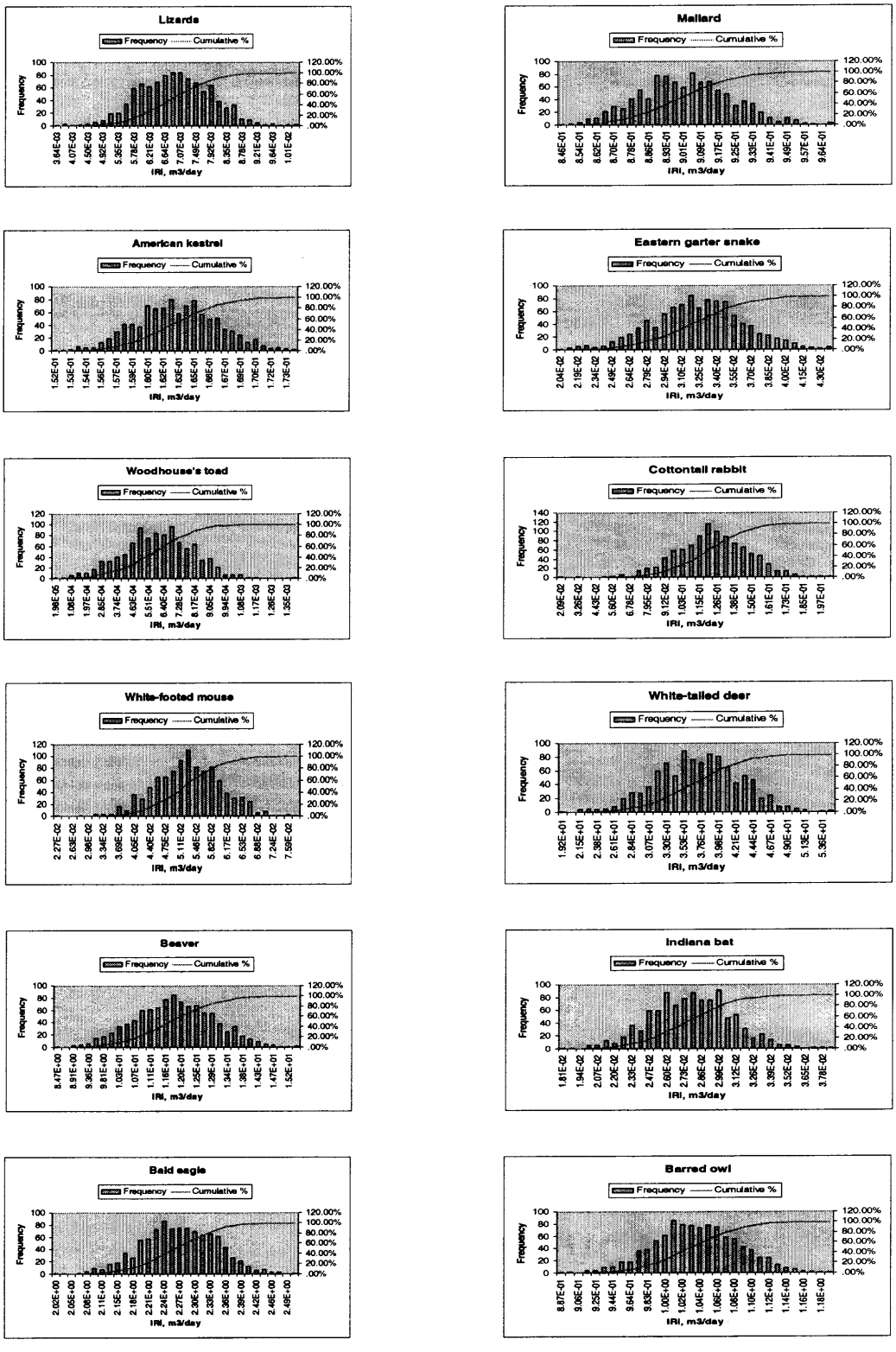
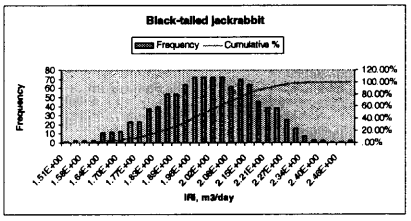
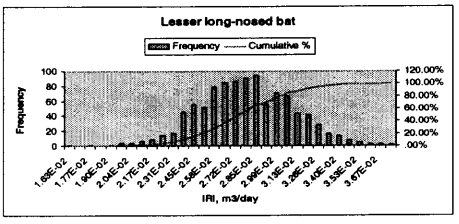
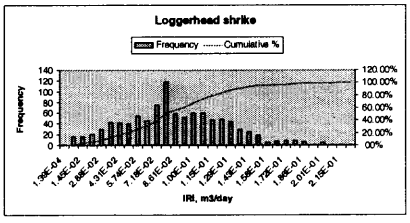
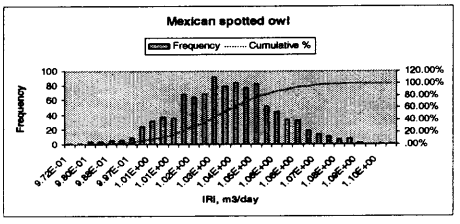


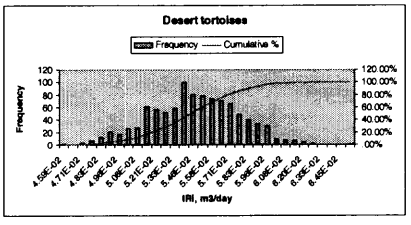
Figure 5.7 Inhalation Rates of APG Terrestrial Animals.

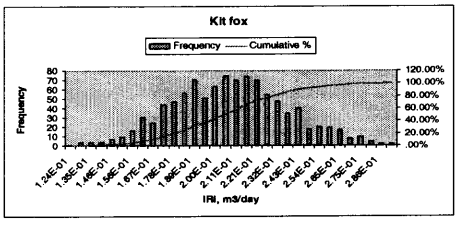


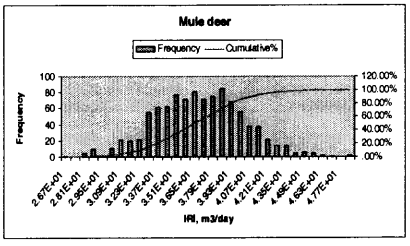


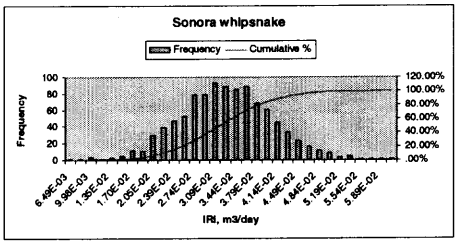


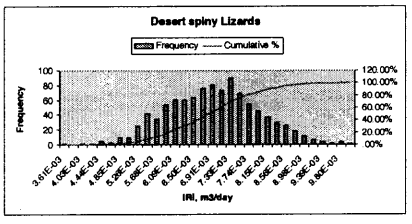


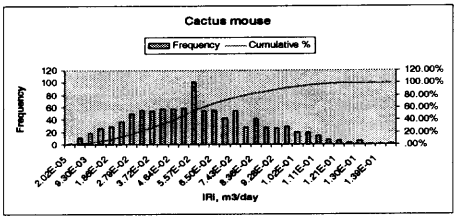












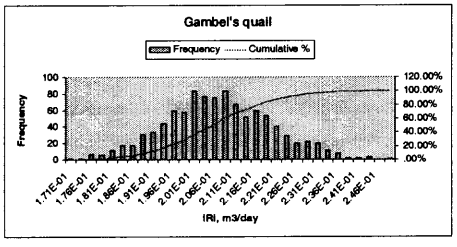


Figure 5.8 Inhalation rates of YPG terrestrial animals.

Woodhouse's toads: $SA = 0.953 * (BW \times 1000)^{0.725}$

Lizards: $SA = 8.42 * (BW \times 1000)^{0.694}$ (salamander applied to lizards)

For turtles, however, there is no equation to estimate surface areas (exclusive of the shell and plastron). For snakes, the general formula for the surface area of a cylinder can be used for approximation if the length and girth are known (U.S. EPA, 1993a). For the trend of the standard deviation, because the surface area is a body weight dependent, the results of each group in terms of the standard deviation show the same trend of the standard deviation of the body weight and the ingestion/inhalation rates. Table 5.6 contains surface area of animals at the APG and YPG sites.

For example, the mule deer and the white tailed deer have among the highest standard deviations for mammals and the bald eagle has the highest standard deviation value for birds. Dermal absorption depends on surface area. Furthermore, this parameter depends on body weight; therefore, the normal distribution is suitable for the surface area behavior (Cullen and Frey, 1999; Hope, 1999). The mean and the standard deviation values are required for normal distribution.

Approach: Similar to ingestion rate, surface area is a function of body weight, it is estimated with allometric equations and is expected to be Gaussian as well (U.S. EPA, 1993a). Monte Carlo simulation method will be propagated into the mean and the standard deviation to construct the distribution for each receptor and randomly the one value to calculate the exposure. Therefore, probability distributions for terrestrial animals from both APG and YPG sites are constructed from the normal distributions for data

Table 5.6 Surface Area

Receptor	Surface area (cm^2)						
	Mean	Min	Max	Range	Min. value as a % of Mean	Max. value as a % of Mean	SD*
Mammal							
Beaver	7558.36	5209.67	10000.8	4791.11	69	132	1197.78
Black tailed jackrabbit	1883.77	1606.32	2520.59	914.27	85	134	228.57
Cactus mouse	409.71	383.85	633.37	249.52	94	155	62.38
Cottontail rabbit	1260.75	869.4	1606.32	736.92	69	127	184.23
Indiana bat	54.94	47.52	86.21	38.69	86	157	9.67
Kit fox	1753.55	1426.8	2238.9	812.10	81	128	203.02
Lesser long nosed bat	54.94	54.94	86.21	31.27	100	157	7.82
Mule-deer	17984.8	17346.8	28468.5	11121.71	96	158	2780.43
White tailed dear	18919.7	7175.17	26711.9	19536.77	38	141	4884.19
White-footed mouse	91.72	71.51	156.4	84.89	78	171	21.22
Birds							
American kestrel	253.07	220.07	267.48	47.41	87	106	11.85
Bald eagle	2967.43	2675.91	3221.07	545.16	90	109	136.29
Barred owl	834.65	604.02	1042.68	438.66	72	125	109.66
Gamble's quail	302.56	220.07	350.55	130.48	73	116	32.62
Loggerhead shrike	130.4	117.1	143.06	25.96	90	110	6.49
Mallard	601.44	507.05	688.92	181.87	84	115	45.47
Mexican spotted owl	743.48	646.34	834.65	188.31	87	112	47.08
Reptiles &Amphibians							
Desert spiny lizard	89.21	67.33	108.93	41.60	75	122	10.4
Lizards	89.21	67.33	108.93	41.60	75	122	10.4
Woodhouse's toad	16.25	11.22	20.74	9.52	69	128	2.38

* Standard deviation (SD) is calculated by using the equation (10)

presented as means and standard deviations. The result contains all possible distributions given the available information (Figures 5.9 – 5.10).

Uncertainty arises when only limited data is available or when there is inadequate knowledge of a situation. Under these conditions, default values and chemical specific values are used. In recent work, U.S. EPA used some parameters such as the soil to skin adherence factor and the contaminant specific dermal absorption factor as default values for studying the exposure of terrestrial animals to chemicals (U.S. EPA, 1989a; U.S.EPA, 1993a; U.S. EPA, 1999b; and U.S. EPA, 2000). Moreover, these values are applied from human exposure values not from animal values (U.S. EPA, 1992b; U.S. EPA, 1989a). Therefore, in this study, the parameters that relate to dermal contact including the soil to skin adherence factor, the contaminant specific dermal absorption factor, the soil contact fraction factor, the site use factor, and the seasonal factor are assigned as a default value and a chemical specific value. The following section will discuss in detail these parameters.

5.2 Default and Chemical Specific Values

In this study, a default value will be applied to the following parameters: soil to skin adherence factor, contaminant specific dermal absorption factor, soil contact fraction, site use factor, seasonal factor, mass fraction of soil or sediment in the diet, and weight fraction of food item in the receptor diet. Details for each parameter are discussed in the following sections.

A default value will be used for parameters that relate to dermal absorption in wildlife. According to U.S. EPA (1993a), dermal estimates are usually expressed as an

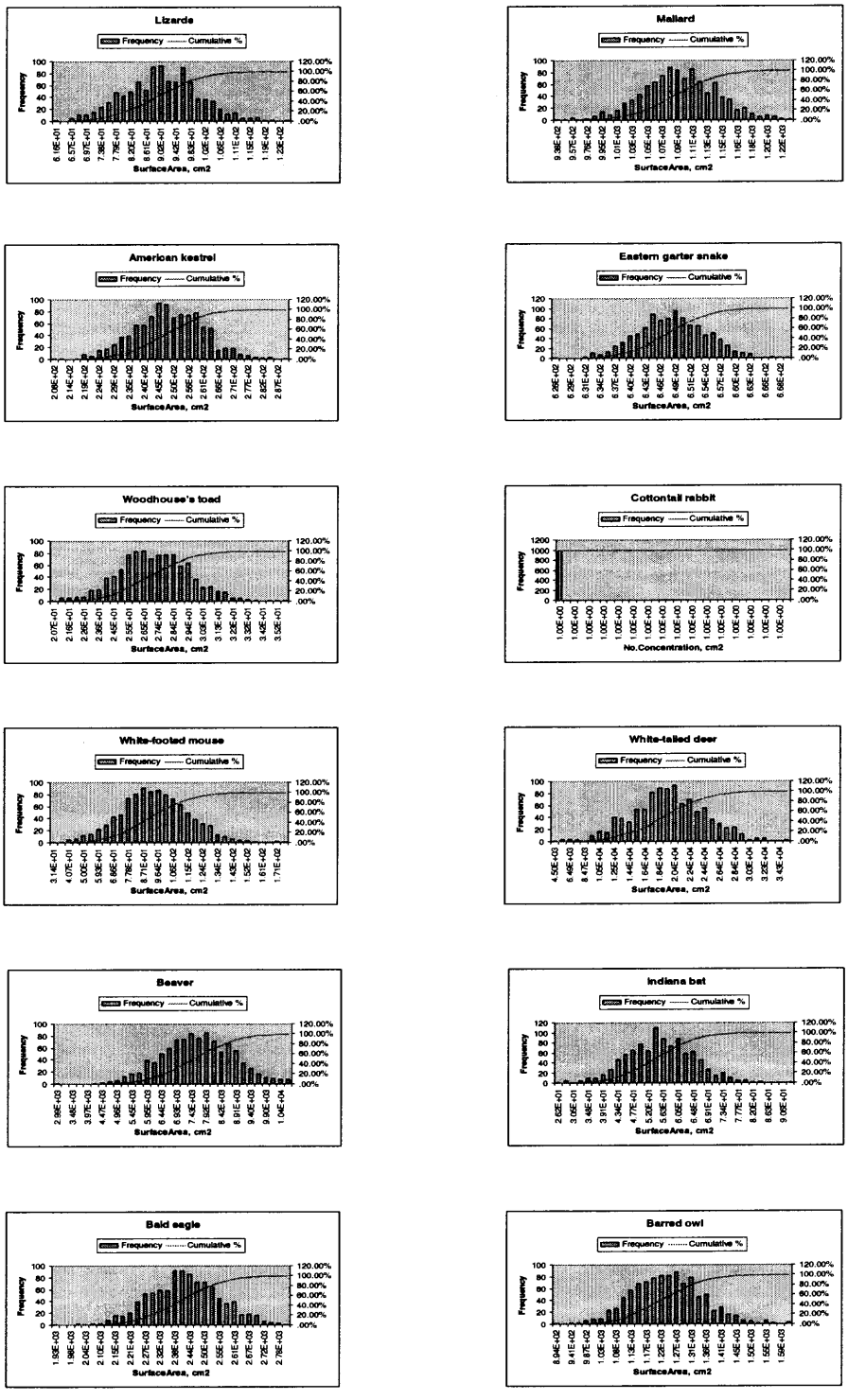


Figure 5.9 Surface Areas of APG Terrestrial Animals.

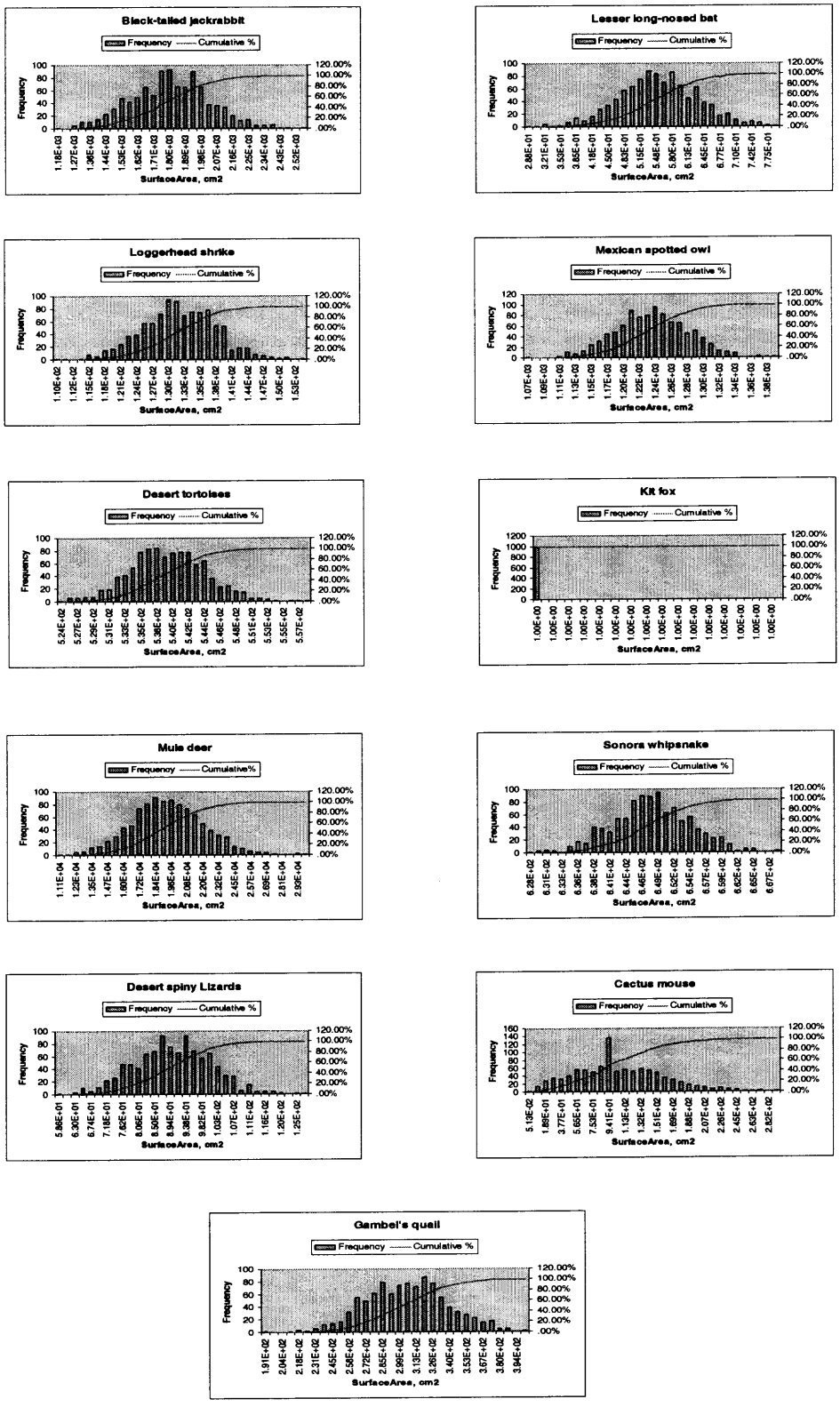


Figure 5.10 Surface Areas of YPG Terrestrial Animals.

absorbed dose resulting from skin contact with a contaminated medium. Dermal exposures may also be a concern for wildlife that swim or burrow. Dermal absorption of contaminants is a function of chemical properties of the contaminated medium, the permeability of the animals' integument, the area of integument in contact with the contaminated medium, and the duration and pattern of contact (U.S. EPA, 1993a). However, the EPA's handbook is not concerned with this dermal absorption pathway. Furthermore, dermal exposure is assumed to be negligible for birds and mammals on most U.S. Department of Energy (DOE) hazardous waste sites (Sample *et al.*, 1997) for the following reason: Feathers of birds, fur on mammals, and scales on reptiles are believed to reduce dermal exposure by limiting the contact of the skin surface with the contaminated media. Moreover, studies assessing the toxicity of dermal exposures for wildlife species are limited. Available studies generally report results for laboratory rodents and are performed by shaving the fur and applying the contaminant directly to the exposed skin (U.S. EPA, 1989a). This type of exposure rarely occurs in the environment. Conditions under which dermal pathways may need to be considered on a site-specific basis include:

1. Species with little or no fur or feathers
2. Species that spend a lot of time exposed to soil (i.e., in burrows)
3. Where the contaminants of concern may be significantly more toxic via the dermal pathway compared to the oral pathway.
4. Where dermal exposures may be substantially higher compared to oral exposures (i.e., pesticides applied directly to trees or soil surfaces).

For birds and mammals, the U.S. EPA (2000) considers two potentially complete exposure pathways: 1) incidental ingestion of soils during feeding, grooming, and preening; and 2) ingestion of food contaminated as a result of the uptake of soil contaminants. Dermal contact was not considered because current information is insufficient to evaluate dermal exposure in their work. Therefore, dermal exposure is expected to be negligible relative to other routes (Sample *et al.*, 1997).

While methods are available to quantitatively assess dermal exposure in humans (U.S. EPA, 1989a), the data necessary to estimate dermal exposures for wildlife are generally not available (U.S. EPA, 1993a; Sample *et al.*, 1997). Dermal exposure may be estimated using the model for terrestrial wildlife presented in the ERA model. The parameters that relate to dermal contact include the soil to skin adherence factor, the contaminant specific dermal absorption factor, the soil contact fraction factor, the site use factor, and the seasonal factor. Details of each parameter are discussed in the following sections.

5.2.1 Soil to Skin Adherence Factor (AF)

Soil adherence to the surface of the skin is a required parameter to calculate dermal dose when the exposure scenario involves dermal contact with a chemical in soil. As discussed in the U.S. EPA (1997a), specific situations have been selected to assess soil adherence to skin of human beings. The studies are based on limited data with results from various factors.

- Soil properties influence adherence. Adherence increases with moisture content, decreases with particle size, but is relatively unaffected by clay or organic carbon content.
- Adherence levels vary considerably across different parts of the body (human). The highest levels were found on common contact points such as hands, knees, and elbows; the least was detected on the face.
- Adherence levels vary with activity. In general, the highest levels of soil adherence were seen in outdoor workers such as farmers and irrigation system installers, followed by people engaged in outdoor recreation, and people engaged in gardening activities. Very high adherence levels were seen in individuals who were in contact with wet soil that might occur during wading or other shore area recreational activities.

For human health, the U.S. EPA (1989a) used the default values within the range 0.2 to 1 mg/cm^2 based on age and activity. Similarly, Finley *et al.* (1994) provided the average estimation value of this factor at 0.25 mg/cm^2 (adult). While data are available to quantitatively assess dermal exposure in humans (U.S. EPA, 1989a; U.S. EPA, 1989b; U.S. EPA, 2001), the data of this factor for wildlife are not available (U.S. EPA, 1993a). For wildlife species, the U.S. EPA (2000) applied the upper end of values for naked human skin to wildlife, which is 1.0 mg/cm^2. Based on the above reasons, the conservative value, 1.0 mg/cm^2 (for human, adult) will be used as a default value for terrestrial animals with dermal exposure. Thus, the uncertainty analysis will not include this parameter, as there is insufficient data to perform an analysis.

Approach: The default value of 1 mg/cm^2 will be used for the soil to skin adherence factor.

5.2.2 Contaminant-Specific Dermal Absorption Factor (α_d)

This factor describes the fraction of a chemical absorbed by skin from direct contact with soil (Hope, 1999). It depends on the exposed surface areas and soil to skin adherence factor (U.S. Army Corps of Engineers, 1998). The values for human health risk assessment may be applicable to mammals (U.S. EPA, 1989a). The exposed surface area (adult) is based on exposure to the head, forearms, hands, and lower legs. These values were calculated from the average of 50th percentile male and female values obtained from the U.S. EPA (1997a). For metals, even though information is limited on the rate and extent of dermal absorption of metals in soil across the skin (U.S. EPA, 1993a), most scientists consider this pathway to be minor in comparison to exposures resulting from direct soil ingestion (Sample *et al.*, 1997; U.S. EPA, 1993b). In addition, ionic species, such as metals, have a relatively low tendency to cross the skin, even when contact does occur (U.S. EPA, 2000). Along with a lack of data to allow reliable estimation of dermal uptake of metals from soil, U.S. EPA Region VIII generally recommends that dermal exposure to metals in soils not be evaluated quantitatively (U.S. EPA, 1998b). Therefore, in this study, the chemical specific value for the dermal absorption factor for metals will be used and there is no uncertainty analysis for this factor.

For organic compounds, especially pesticides, the U.S. Army Corp of Engineers (1998) estimated the human dermal absorption factors for pesticides based on data from the U.S. EPA (1997a). As a result, the value of 0.13 mg/kg-body burden / mg/kg-day will

be applied as the dermal absorption factor for pesticides (U.S. EPA, 2000). No uncertainty analysis will be included for this factor.

Approach: The default value for organic compounds (pesticides) is 0.13 mg/kg-body burden /mg/kg-day.

5.2.3 Proportion of Total Surface Area in Contact With Soil Per Day (P_c)

From human studies, soil contact (dermal) exposure was expected to occur at the hands, legs, arms, neck, and head with approximately 26% and 30% of the total surface area exposed for adults and children, respectively (U.S.EPA, 1989a). Based on clothing that prevents dermal contact and, subsequently, absorption of contaminants, U.S. EPA (1989a) suggests that roughly 10% to 25% of the skin area may be exposed to soil. Thus, applying 25% or 0.25 to the total body surface area results in defaults for adults (human). For animal studies, Hope (1995) applied the value of 0.22 for the proportion of total surface area in contact with soil for mammals, based on a *Peromuscus* mouse. The CRCIA model (PNNL, 1998) also applied this value as a default (0.22) to estimate the contaminant exposure for mammals. Hope (1999) suggests professional judgment to adjust this proportion for other receptors, such as birds with brood patches or for unfledged or hairless newborns. Therefore, the value of 0.22 per day will be set as a default value for the proportion of total surface area in contact with soil in this study because this value is derived from an animal (mouse) study. Therefore, uncertainty analysis will not be performed for this parameter.

Approach: The default value of 0.22 will be used for the fraction of surface area in contact with soil per day.

5.2.4 Site Use Factor (θ)

The site use factor is defined as the ratio of the contaminated area to foraging area for a given receptor species, such that $0 \leq \theta \leq 1$ (U.S. EPA, 1993a; Hope, 1999; Sample *et al.*, 1997). An animal whose total home or foraging range area is equal to or smaller than the contaminated area will have a default value of 1.0 (Hope, 1999; PNNL, 1998).

Approach: The default value of 1.0 will be used for the site use factor.

5.2.5 Seasonal Factor (ψ)

The seasonal factor is the fraction of the number of days per year a receptor spends at, or is active on, the contaminated area. A seasonal factor is used to account for the effects of migration, hibernation, or other behavior patterns on frequency of contact with contaminated media or prey (Sample *et al.*, 1997). Year-round, non-hibernating, non-seasonal species will have a default value of 1.0 (= 365 days/year) (Hope, 1999; PNNL, 1998).

Approach : The default value as 1.0 will be used for the seasonal factor.

5.2.6 Percent by Mass of Soil or Sediment in The Diet (FS)

Percent soil in the diet for some species is included in Table 5.7 (U.S. EPA, 1993a). The sandpiper group, which feeds on mud-dwelling invertebrates, was found to have the

highest rates of soil/sediment ingestion (30, 18, 17, and 7.3% of diet, respectively, for semipalmated, western, stilt, and least sandpipers). Wood ducks also can ingest a high proportion of sediment (24 %) with their food. Relatively high soil intakes were estimated for the raccoon (9.4 %), an omnivore, and the woodcock (10.4 %), which feeds extensively on earthworms. The Canadian goose, which browses on grasses, also exhibited a high percentage of soil in its diet (8.2 %). Soil ingestion was lowest for the white-footed mouse, meadow vole, fox, and box turtle (<2, 2.4, 2.8, and 4.5 %, respectively). Therefore, the value used for this parameter is based upon the specific receptor.

Approach: The specific value for each receptor will be used for the mass fraction of soil/sediment in the diet (Table 5.7).

5.2.7 Weight Fraction of Food Item in Receptor Diet (FR_{fk})

Wildlife can be exposed to contaminants in one or more components of their diet, and the different components can be contaminated at different levels (U.S. EPA, 1993a). FR_{fk} is a function of the degree of overlap of the k^{th} type of simplest case, for example, if the k^{th} component of an animal's diet were salmon, FR_k for salmon would equal the fraction of the salmon consumed that is contaminated at level of contaminant concentration in the k^{th} type of food. Table 5.8 contains the fraction of food item in receptor diet from CRCIA model (PNNL, 1998). The default value, similar to the percent by mass of soil or sediment in the diet (FS), is based on the specific receptors.

Table 5.7 Percent by Mass of Soil/Sediment in the Diet (FS) (U.S. EPA, 1993a)

Species	Mass fraction of soil/sediment in the diet (% of diet, dry weight basis)
Birds	
Canada goose	8.2
Mallard	<2
Wood duck	11
Blue winged teal	<2
Ring necked duck	<2
American Woodcock	10.4
Semipalmated sandpiper	30
Western sandpiper	18
Stilt sandpiper	17
Least sandpiper	7.3
Mammals	
Red fox	2.8
Raccoon	9.4
White-footed mouse	<2
Meadow vole	2.4
Jackrabbit	6.3
Hispid cotton rats	2.8
Shorebirds	10-60
Reptiles and Amphibians	
Eastern painted turtle	5.9
Box turtle	4.5

Table 5.8 Weight Fraction of Food Item in Receptor Diet (FR_{fk}), (PNNL, 1998)

Weight fraction of food item in receptor diet (kg, food /kg, diet)										
Species	**Fungi**	**Black cottonwood**	**Dense sedge**	**Fern**	**Mulberry**	**Reed canary grass**	**Rushes**	**Tulle**	**Columbia yellow cress**	**Terrestrial arthropods**
Fungi	0	0	0	0	0	0	0	0	0	0
Black cottonwood	0	0	0	0	0	0	0	0	0	0
Dense sedge	0	0	0	0	0	0	0	0	0	0
Fern	0	0	0	0	0	0	0	0	0	0
Mulberry	0	0	0	0	0	0	0	0	0	0
Reed canary grass	0	0	0	0	0	0	0	0	0	0
Rushes	0	0	0	0	0	0	0	0	0	0
Tulle	0	0	0	0	0	0	0	0	0	0
Columbia yellow cress	0	0	0	0	0	0	0	0	0	0
Terrestrial arthropods	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0
Lizards (Utah)	0	0	0	0	0	0	0	0	0	0.9
Western aquatic garter snake	0	0	0	0	0	0	0	0	0	0.1
Muskrat	0	0	0.05	0	0	0	0.05	0.375	0.375	0
Beaver	0	0.5	0	0	0.5	0	0	0	0	0
Raccoon	0	0	0.1	0	0.05	0	0.1	0.2	0	0.1
Coyote	0	0	0	0	0.02	0	0	0	0	0.05
Weasel	0	0	0	0	0	0	0	0	0	0.005
Mule deer	0	0.3	0.1	0	0.3	0.1	0.1	0.1	0	0
Harvest mouse	0	0	0.4	0	0	0.4	0.1	0	0	0.1
Woodhouse's toad - adult	0	0	0	0	0	0	0	0	0	0.25
American coot	0	0	0	0	0	0	0	0.035	0.035	0.02
Common snipe	0	0	0	0	0	0	0	0	0	0.05
Bufflehead	0	0	0	0	0	0	0	0.04	0.04	0.02
Canada Goose	0	0	0.05	0	0	0.2	0.2	0.125	0.125	0
Mallard	0	0	0.05	0	0	0.05	0.1	0.175	0.175	0
American white pelican	0	0	0	0	0	0	0	0	0	0
Forster's tern	0	0	0	0	0	0	0	0	0	0
California quail	0	0	0.1	0	0	0.8	0.07	0	0	0.03
Cliff swallow	0	0	0	0	0	0	0	0	0	0.1
Great blue heron	0	0	0	0	0	0	0	0	0	0.04
Bald eagle	0	0	0	0	0	0	0	0	0	0
Northern harrier	0	0	0	0	0	0	0	0	0	0
American kestrel	0	0	0	0	0	0	0	0	0	0.01

Approach: The specific value (Table 5.8) for each receptor will be used for the weight fraction of food item in receptor diet.

5.2.8 Depuration Rate (k_e)

The depuration or elimination rate is the rate at which an absorbed containment dose is released from tissues and then excreted (U.S. EPA, 1996c). The depuration rate is expressed as a first order rate constant in day^{-1}.

Uptake and depuration rate constants have been evaluated using a simple first order one-compartment model (Uno *et al.*, 1997; Liao *et al.*, 2002). The equation describing the kinetic uptake and depuration can be written as

$$\frac{dC_t}{dt} = k_u C_w - k_d C_t \qquad (10)$$

Where C_t is the concentration in the receptor at time (t), C_w is the concentration in the water, and k_u and k_d are the uptake and depuration rate constants, respectively. When C_w is zero regarding depuration rates monitoring condition, then Equation 10 reduces to

$$\frac{dC_t}{dt} = -k_d C_t \qquad (11)$$

Integrating equation (11)

$$\int_{C_0}^{C_t} \frac{dC_t}{C_t} = -k_d \int_0^t dt \qquad (12)$$

$$\ln \frac{C_t}{C_0} = -k_d t \qquad (13)$$

or $$\log C_t = \log C_0 - (k_d / 2.301)t \qquad (14)$$

where C_0 is the concentration in receptor at the initial time.The half life, $t_{1/2}$, is

$$t_{1/2} = \frac{\ln 2}{k} = \frac{0.693}{k} \qquad (15)$$

For aquatic species, Blackmore and Wang (2002) studied the depuration rate of Cd and Zn from mussel. The exposure ranged from high to low concentrations over 7-21 days. They reported that an initial rapid loss of both metal occurred during the first 4-5 days followed by a second slower loss for the remaining depuration period (5-32 days). The Cd (0.007-0.012 day^{-1}) and the Zn (0.034-0.038 day^{-1}) depuration rates were not significantly affected by concentration.

Gomez-Ariza *et al.* (1999) studied the elimination of tributyltin (TBT) in clams, *V.decussata*. The depuration rate was studied in a flow through system for a period of 100 days and they reported the depuration rate constants of 0.02day^{-1}. Uno *et al.* (1997) studied the uptake and depuration rate of pesticides in shellfish in Japan (Table 5.9). The test pesticides used were p-nitrophenyl 2,4,6-trichlorophenyl ether (CNP) and Thiobencarb. The results showed the bivalve depuration rate constants of CNP and Thiobencarb were 0.045 and 0.06 day^{-1}. For the river snail, depuration rate constants of CNP and Thiobencarb were 0.10 and 0.14 day^{-1}, respectively. These results indicate that the depuration rate depends on both the receptor and chemical.

Blanco *et al.* (2002) studied the depuration of amnesic shellfish poisoning (ASP) by domoic acid in the king scallop *Pecten maximus*. The depuration of the domoic acid

Table 5.9 Uptake and Depuration Rate of Shellfish in Japan (Uno *et al.*, 1997)

Species of Shellfish	**Year**	**Rate**	**CNP**	**Thiobencarb**
Bivalve (Corbicula leana)	1992	Uptake	626	99
		Depuration	0.045	0.055
	1993	Uptake	243	183
		Depuration	0.045	0.06
	Laboratory	Uptake	338	140
		Depuration	0.054	0.049
River snail (Cipangopludina chinenisis)	1992	Uptake	50	56
		Depuration	0.10	0.14
	Laboratory	Uptake	66	28
		Depuration	0.16	0.22

Unit: Uptake rate = L/g-day, Depuration rate = day^{-1}

from fractions (digestive gland, adductor muscle, gonad and kidney and gills+mantle) of scallop was studied over 295 days. Blanco *et al.* reported that overall domoic acid depuration rates of *Pecten maximus* were very slow regardless of tissue (0.00664 day^{-1}). Sericando *et al.* (1996) studied the accumulation and depuration of organic contaminants by the American oyster (Crassostrea virginica) in Hanna Reef (as uncontaminated area) and Ship Channel at Galveston Bay, Texas. In their study, they observed the polynuclear aromatic hydrocarbon (PAH) concentration as a function of time. They reported that the PAHs uptake leveled off at 48 days, and subsequently, the depuration occurred (Table 5.10)

The study confirmed that the depuration rate constant is both receptor and chemical dependence. Furthermore, Marr *et al.* (1996) studied the Cu uptake by rainbow trout at different concentrations. The study showed that the Cu concentration increased between 0 and 40 days and appeared to reach steady state subsequently. The authors described that the fish's effective accumulation capacity is increased by exposure concentration and the Cu depuration rates were concentration dependent. However, in this study, the authors only reported that the Cu depuration rate of rainbow trout was observed to be slow but did not report or present the data.

From the literature review above, depuration rate has been used to estimate the bio-concentration factor (BCF) of aquatic species, as BCF is the ratio between the uptake rate and the depuration rate of contaminant. Deputation rate constants are directly applied for the terrestrial animal exposure. Hope (1995) recommended that the constant may be obtained from the literature or from the results of site-specific investigations. Few data have been reported for depuration rates of terrestrial animals for metals. Hendriks (1995)

Table 5.10 Depuration Rate of Selected PAHs in Oysters (Sericano *et al.*, 1996)

PAHs	**Depuration rate (per day)**	
	Hanna Reef	**Ship Channel**
Fluoranthene	0.027	0.022
Pyrene	0.069	0.058
Benzo(a)anthracene	0.053	0.046
Chrysene	0.058	0.043
Benzo(e)pyrene	0.058	0.043
Benzo(a)pyrene	0.077	0.069
Indono(1,2,3,-c,d)pyrene	0.069	0.063

reported the depuration of cadmium and mercury of mammal (rat) from which the biological half-life time was estimated (Table 5.11).

Approach: In ERA model, the depuration rate is accounted for contaminant in the body burden of terrestrial receptors. The data sources for the depuration of the terrestrial animals are limited resulting in a potentially significant error. Therefore, to reduce an error, specific depuration rates will be considered as a chemical specific value for each metal (Table 5.11)

The next section will provide the parameters related to aquatic organisms, specifically the bio-concentration factor (BCF). Both aquatic animals and plants can accumulate contaminants from water to their bodies and BCF indicates the degree to which a chemical may accumulate in aquatic organisms.

5.3 Aquatic and Plant Species

The following sections contain parameters for aquatic and plant species. The study focuses on how to perform uncertainty analysis using these parameters when data are coming from experimental values derived from literature review. The limitations of the factors that cause an error from both data sources are discussed. Also, the sources of the data used to derive the estimation equations are provided in this section. Parameters include the bio-concentration factor (BCF), the soil to plant bio-concentration factor, the root concentration factor, and the plant-air partition coefficients.

Table 5.11 Metal Depuration Rates in the Terrestrial Animals (Hendriks, 1995: Jørgensen *et al.*, 1991)

Metal	Depuration rate (day^{-1})
Cadmium	0.001
Chromium	0.6
Copper	0.02
Lead	0.024
Mercury	0.023
Nickel	1.3
Uranium-234, 238	0.002
Zinc	0.08

5.3.1 Aquatic Species

5.3.1.1 Bio-Concentration Factor (BCF). The bio-concentration factor (BCF) is a ratio of the chemical concentration in an aquatic organism to its concentration in water at equilibrium where values were generated from field and/or laboratory data (US.EPA, 2003; PNNL, 1998; Sample *et al.*, 1998).The associated distributions have been observed as skewed, which has led to the use of the logarithmic transformation of the parameter to obtain the lognormal distribution (Traas *et al*, 1996; Verhaar *et al.*, 1999; Samsoe-Petersen *et al.*, 2002; and Liao *et al.*, 2003).

The Ecotox database (U.S. EPA, 2003) is an updated source that reports peer-reviewed BCF values. This database, which was created by the U.S. EPA, Office of Research and Development (ORD) and the National Health and Environmental Effects Research Laboratory (NHEERL), Mid-Continent Ecology Division, is a source for locating single chemical toxicity data for aquatic life, terrestrial plants, and wildlife. To retrieve the data from the Ecotox database, at least some of the following information should be known: scientific or common names of receptors and chemical names or chemical CAS numbers. Table 5.12 shows the BCF data for some chemicals. The data contain the scientific and common names of receptors; number of samples taken; the range of data; the mean value; and the standard deviation.

Both the mean and the standard deviation were calculated by using the lognormal distribution formula (U.S. EPA, 1999e). DDT, one of the halogenated hydrocarbon insecticides, has been widely studied to determine its bio-concentration factor. There are 35 species of receptors that have been reported in the Ecotox database for this chemical. Also, extensive use of the basket-tail dragonfly as a sample receptor has resulted in 33

Table 5.12 BCF Values (L/kg) from the Ecotox Database (U.S. EPA, 2003)

Scientific name	Common name	No of samples	Ranges	Geometric* mean	SD**
DDT (CAS#50293)					
Aedes aegypti	Yellow fever mosquito	3	16273-21571	18054.29	2812.39
Algae	Algae, algal mat	2	4720-5420	5057.90	495.77
Artiemia salina	Brine shrimp	4	233-6184	704.41	471.78
Astacus, leptodactylus	Crayfish	1	240*		
Blepharisma intermedium	Ciliate	8	861.6-59999	19781.37	43027.87
Chironomus, Midge	Midge	3	7800-47800	20904.01	23995.41
Cipangopaludina japonica	Mud snail	1	3660		
Culex pipiens quinquefasciata	Mosquito	3	110-515	210.65	199.55
Cyprinus carpio	Common, mirror, colored carp	3	1330-5000	2514.24	1870.09
Daphnia	Water flea	12	1170-114100	6104.41	24897.86
Ephemera danica	Mayfly	8	440-3060	1992.22	2369.08
Epitheca sp.	Baskettail dragonfly	33	200-2700	712.88	474.74
Gambusia affinis	Western mosquito fish	3	300-344	314.00	24.85
Gammacus fasciaus	Scud	3	4600-32600	10466.55	9255.26
Heterocypris incongruens	Ostracod	2	4771-8111	6220.74	2418.88
Hexagenia bilineata	Mayfly	3	9400-32600	17232.73	11853.20
Indonaia caeruleu	Unionid clam	8	40-684	255.95	263.45
Ischnura verticalis	Damselfly	1	3500		
Labidesthes sicculus	Brook silverside	2	218-306	258.28	62.83
Lagodon rhomboides	Pinfish	2	10000-38000	19493.59	23374.79
Lepomis cyanellus	Green sunfish	1	17500		
Lepomismacrochirus	Bluegill	3	23000-25000	23986.10	956.05
Libellula	Dragonfly	1	910		
Micropogonnias undulatusr	Atlantic croaker	2	10000-38000	22277.69	26713.21
Neanthes grubei	Polychaete	1	9		
Nereis arenaceodentata	Polychaete worm	1	1.5		
Notemigonus crysoleucas	Golden shiner	1	100000		
Oncorhynchus mykiss	Rainbow trout, donaldson trout	13	2700-97100	47274.32	56718.99
Orconectes nais, Crayfish	Crayfish	3	880-2900	1749.98	1190.73
DDT (CAS#50293)					
Ostracoda	Ostracod, seed shrimp subclass	2	716-1418	1007.62	516.71
Palaemonestes kadiakensis	Grass shrimp, freshwater prawn	3	1500-5000	3027.52	2099.22
Pimephales promelas	Fathead minnow	2	29400-99000	53949.98	56319.27
Salvelinus namaycush	Lake trout, siscowet	3	44286-52750	47282.73	4519.59
Simocephalus	Water flea	10	8813-148842	30741.51	30571.11
Siphlonurus	Mayfly	3	10200-22900	16716.88	7594.54
Tetrahymena pyriformis	Ciliate	10	1.92-11.89	6.72	4.95

Table 5.12 BCF Values (L/kg) from the Ecotox Database (continued)

Scientific name	Common name	No of samples	Ranges	Geometric Mean*	SD**
Biphenyl (CAS#92524)					
Chlorella fusca	Green algae	4	540	540.00	0
Leuciscus idus	Ide, silver or golden orfe	2	280-281	280.50	0.58
Leuciscus idus melanotus	Carp	1	280		
Chlorobenzene (CAS#108907)					
Chironomus decorus	Midge	1	11		
Chlorella fusca	Green algae	2	50	50.00	0.00
Culex quinquefasciatus	Southern house mosquito	1	1292		
Daphenia magna	Water flea	1	2789		
Gambusia affinis	Western mosquito fish	1	645		
Leuciscus idus	Ide, silver or golden orfe	2	70-75	72.46	3.54
Oedogonium cardiacum	Green algae	1	4185		
Physa	Pouch snail	1	1313		
Selenastrum capricornutum	Green algae	1	2172		
Chromium (CAS#7440473)					
Mytilus edulis	Common bay mussel, blue mussel	2	20-40	28.28	14.74
Oncorhynchus mykiss	Rainbow trout, donaldson trout	4	1.03-1.34	1.31	0.15
Bis (Nitrato-o, o') dioxouranium (CAS#10102064)					
Austrocochlea constrita	Zebra winkles	3	2.4-4.6	3.59	1.31
Oncorhynchus mykiss	Rainbow trout, donaldson trout	2	19.8-37.2	27.14	12.73
Pachygrapsus laevimanus	Crab	2	6.8-17.8	11.00	8.44

* Calculated by using the equation (18), ** Calculated by using the equation (20)

separate studies in the data providing a wide range (200 to 2700 L/kg) of BCF values with a standard deviation of 474.74 L/kg. Chlorobenzene, another example, has nine receptors that have been studied, and seven of nine receptors showed only one BCF value. Another organic compound is biphenyl, of which three receptors have been studied. In the case of metals, BCF values for chromium, uranium, tantalum, molybdenum and vanadium were needed. As shown in Table 5.12, in the case of chromium, there are two receptors that have reported BCF values. Uranium has been reported in the database only in the bis (nitro-o, o') dioxouranuim form. Only three receptors for Uranium have been studied. There is no BCF data for tantalum, molybdenum, and vanadium in the Ecotox database (2003). The lognormal distribution is used to analyze uncertainty for this data. The formula of the lognormal distribution is as follows (Benjamin and Cornell, 1970:Gilbert, 1987; U.S. EPA, 1997c).

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma_y x}\exp\{-\frac{[\ln(x) - \ln(m)^2]}{2\sigma_y^{\ 2}}\} \tag{16}$$

where m is the median of parameter (m = exp ($\mu_{\ln(x)}$)) and σ_y is the geometric standard deviation of ln (x).

The sample geometric mean and the standard deviation, σ, are computed as: is computed as:

$$m = \exp(\mu_{\ln(x)}) \tag{17}$$

$$\mu = \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i = \frac{1}{n}\sum_{i=1}^{n} \ln x_i \tag{18}$$

$$\sigma = m[\exp(\sigma_y^2 - 1)]^{1/2} \tag{19}$$

Approach: To perform an uncertainty analysis for BCF, Equations (17) through (19) will be used to calculate the mean and standard deviation. The specific receptors and associated laboratory data will be used as the input data for probabilistic distribution analysis. One of the most up-to-date data sources for BCF values is the Ecotox database; therefore, the BCF input value in this study is based on this database. The approach involves the following steps:

1. Retrieve the data from the Ecotox database by searching with either chemical names or receptor names
2. Gather data, then transform the data into the natural log form
3. Calculate the geometric mean by using equation (17), and the standard deviation by using equation (19)

In case there is one value, it can be assumed that the value is the mean and the coefficient of variance (CV) is 1 (McKone, 1993; Currie *et al.*, 1994). Because the coefficient of variance is the ratio of the standard deviation to the mean value, in this conservative case, the standard deviation will be equivalent to the mean. The standard deviation will be propagated into the error of the exposure model. If there is no data available in the Ecotox database, the estimation method will be used. The estimation method for BCFs will be discussed in the following section.

5.3.1.2 Estimation Methods for theBio-Concentration Factor. The Ecotox database is one of the sources where we can retrieve the BCF value for the receptors or contaminants of interest. However, when data are not available, the estimation method must be used. The following equation is used to estimate the BCF from water solubility

(S) for both organic and inorganic compounds (Lyman *et al.*, 1990, Kenaga and Goring, 1980, Sample *et al.*, 1996)

$$\text{Log BCF} = 2.791 - 0.564 \log S \pm 1.99,\ n=36,\ r^2 = 0.49, \quad (20)$$

Units: BCF = L/Kg and S= mg/L

Kenaga and Goring reported the order of magnitude or the 95% confidence limits from the calculated value as ± 1.99 (or ± 98 L/kg). The BCF estimation equation is derived from laboratory experiments by a number of investigators studying a variety of fish species (brook trout, rainbow trout, bluegill sunfish, fathead minnow, and carp) and 36 organic chemicals (Table 5.13). Therefore, when the estimated equation is used, the error (± 98 L/kg of BCF) should be applied to the uncertainty analysis.

5.3.2 Plants Species

Plants can be target receptors for contaminants, as well as the first point where contaminants gain access to a terrestrial food chain (U.S. DOE, 1998). Uptake of contaminants by plants is a complex process, which is affected by contaminant physiochemical properties, environmental conditions, and plant characteristics (Farago, 1994). Plant parameters include the soil to plant bio-concentration factor, root concentration factor, and plant-air partition coefficients.

Table 5.13 Water Solubility (mg/L) and BCF Data (Kenaga and Goring, 1980)

Chemical	Solubility (mg/L)	BCF (L/kg)
DDT	0.0017	61600
Dieldrin	0.022	5800
Endrin	0.024	4050
Heptachlor	0.03	17400
Lindane	0.15	325
Methoxychlor	0.003	185
Toxaphene	0.4	26400
Kepone	3	8400
Chlorobenzene	448	12
p-Dichlorobenzene	79	215
Hexachlorobenzene	0.035	8600
Pentachlorobenzene	0.135	5000
1,2,4,5-Tetrachlorobenzene	6	4500
1,2,4-Trichlorobenzene	30	491
4-Chlorobiphenyl	1.65	590
4,4-Dichlorobiphenyl	0.062	215
Aroclor 1016, 1242	0.085	48980
Aroclor 1248	0.017	72950
Aroclor 1254	0.01	45600
2,2,4,4,5,5-Hexachlorobiphenyl	0.001	46000
Diphenyloxide	21	196
4-Chlorodiphenyloxide	3	736
x-sec-Butyl-4-chlorodiphenyloxide	0.14	298
x-Hexyl-x-chlorodiphenyloxide	0.076	18000
x-Dodeca-x-chlorodiphenyloxide	0.052	12
Biphenyl	7.5	340
Diamidaphos	50000	1
Chlorpyrifos	0.3	450
Leptophos	2.4	750
Diazinon	40	35
Di-2-ethylhexylphthalate	0.6	380
Trifluralin	0.6	4570
Atrazine	33	0
Simazine	3.5	1
3,5,6-Trichloro-2-pyridnol	220	3

5.3.2.1 Soil to Plant Bio-Concentration Factors. The soil-to-plant bio-concentration values represent the plant uptake of compounds from soil. In the ERA model, the K_p and the B_v represent the ratio of the contaminant concentration in plant parts to contaminant concentration in soil for the organic and the inorganic compounds, respectively. The K_{ps1} represents the plant-soil coefficient for a root-zone soil to roots. The K_{ps2} expresses the ratio of the contaminant concentration in the aboveground plant parts (mg/kg plant fresh mass) to the contaminant concentration (mg/kg) in a dry root-zone soil. The K_{pa} represents the ratio of the contaminant concentration in the aboveground plant parts (mg/kg) to the contaminant concentration in the air gases and bound to the particles. The bio-concentration factor for the inorganic contaminants present is B_v, which is the ratio of contaminant concentration in vegetative plant parts to contaminant concentration in soil. U.S EPA (1999a; 1999b) identifies factors for both the organic and the inorganic compounds. The B_v and K_{pa} of some metals are provided in Table 5.14.

For inorganic compounds, experiments conducted for mercurie chloride and methyl mercury included parameters studied with more than one datum. Analyzing the data by using the Equations (18)-(20), the overall error, which represents the standard deviation, is 1.68×10^{-2} mg/kg plant per mg/kg soil for K_p. The organic contaminants include dioxins and furans; polynuclear aromatic hydrocarbons; polychlorinated biphenyls; nitro-aromatics; phthalate esters; volatile organic compounds; and pesticides. By analyzing the data for each group and using Equations (17) - (19), the results reveal the geometric means and standard deviations (Table 5.15). The standard deviation of K_p for each group is varied regarding a wide range of the group data.

Table 5.14 Soil to Plant Bio-Concentration Factors and Air to Plant Bio-Transfer Factor for The Metals (U.S. EPA, 1999a)

CHEMICAL	B_v (mg/kg plant/mg/kg soil)	K_{pa} (mg/m^3)
Inorganic		
Aluminum	4.00E-03	0.00E+00
Antimony	2.00E-01	0.00E+00
Arsenic	3.60E-02	0.00E+00
Barium	1.50E-01	0.00E+00
Beryllium	1.00E-02	0.00E+00
Cadmium	3.64E-01	0.00E+00
Chromium	7.50E-03	0.00E+00
Copper	4.00E-01	0.00E+00
Lead	4.50E-02	0.00E+00
Mercuric chloride	3.75E-02	0.00E+00
Methyl mercury	1.37E-01	0.00E+00
Nickel	3.20E-02	0.00E+00
Selenium	1.60E-02	0.00E+00
Silver	4.00E-01	0.00E+00
Thallium	4.00E-03	0.00E+00
*Geometric mean**	*4.61E-02*	-
*Geometric standard deviation***	*1.68E-01*	-

* Calculated by using the equation (17)
** Calculated by using the equation (19)

Table 5.15 Soil to Plant Bio-concentration Factors and Air to Plant Bio-Transfer Factor for the Organic Compounds (U.S. EPA, 1999a)

CHEMICAL	K_p (mg/kg plant/mg/kg soil)	K_{pa} (mg/m^3)
Dioxins and furans		
2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD)	5.60E-03	6.55E+04
1,2,3,7,8-Pentachlorodibenzo (p) dioxin (1,2,3,7,8-PeCDD)	5.20E-03	2.39E+05
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin (1,2,3,4,7,8-HxCDD)	1.70E-03	5.20E+05
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin (1,2,3,6,7,8-HxCDD)	6.70E-04	5.20E+05
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin (1,2,3,4,6,7,8-HpCDD)	2.90E-04	9.10E+05
Octachlorodibenzo-p-dioxin (OCDD)	6.70E-05	2.36E+06
2,3,7,8-Tetrachlorodibenzofuran (2,3,7,8-TCDF)	4.50E-03	4.57E+04
Octachlorodibenzo-p-furan (OCDF)	9.00E-05	2.28E+06
1,2,3,7,8-Pentachlorodibenzo-p-furan (1,2,3,7,8-PeCDF)	1.10E-03	9.75E+04
2,3,4,7,8-Pentachlorodibenzo-p-furan (2,3,4,7,8-PeCDF)	9.00E-03	9.75E+04
2,3,4,6,7,8-Hexachlorodibenzo-p-furan (2,3,4,6,7,8-HxCDF)	3.80E-03	1.62E+05
1,2,3,4,6,7,8, -Heptachlorodibenzo-p-furan (1,2,3,4,6,7,8-HpCDF)	6.20E-05	8.30E+05
1,2,3,4,7,8,9-Heptachlorodibenzo-p-furan (1,2,3,4,7,8,9-HpCDF)	2.20E-03	8.30E+05
*Geometric mean**	*1.02E-03*	*3.46E+05*
*Geometric standard deviation***	*4.87E-03*	*7.47E+05*
Polynuclear aromatic hydrocarbons (PAHs)		
Benzo (a) pyrene	0.00E+00	2.25E+05
Benzo (a) anthracene	2.02E-02	1.72E+04
Benzo (b) fluoranthene	1.01E-02	3.65E+04
Benzo (k) fluoranthene	1.01E-02	5.40E+05
Chrysene	1.87E-02	5.97E+04
Dibenzo (a, h) anthracene	6.40E-03	4.68E+07
Ideno (1,2,3-cd) pyrene	3.90E-03	2.67E+08
*Geometric mean**	*9.94E-03*	*6.64E-01*
*Geometric standard deviation***	*6.91E-03*	*6.62E+08*

Table 5.15 Soil to Plant Bio-concentration Factors and Air to Plant Bio-transfer Factor for the Organic Compounds (continued)

Chemical	K_p (mg/kg plant/mg/kg soil)	K_{pa} (mg/m^3)
Volatile organic compounds		
Acetone	5.20E+01	1.13E-03
Acrylonitrile	2.78E+01	1.04E-03
Chloroform	2.90E+00	1.65E-03
1,4-Dioxane	5.53E+01	5.93E-03
Formaledehyde	2.46E+01	4.65E-04
Vinyl chloride	8.43E+00	2.95E-06
*Geometric mean**	*1.91E +01*	*1.15E+00*
*Geometric standard deviation***	*3.14E+01*	*1.67E-02*
Pesticides		
4,4'-DDE	9.37E-03	2.08E+03
Heptachlor	4.89E-02	2.09E+03
Hexachlorophene	1.70E-03	1.23E+10
*Geometric mean**	*9.20E-03*	*3.77E+05*
*Geometric standard deviation***	*3.66E-02*	*1.48E+23*
Polychlorinated biphenyls (PCBs)		
Aroclor 1016	1.00E-02	7.52E+01
Aroclor 1254	1.00E-02	3.09E+02
*Geometric mean**	*1.00E-02*	*1.52E+02*
*Geometric standard deviation***	*0.00E+00*	*2.00E+02*
Nitroaromatics		
1,3-Dinitrobenzene	5.32E+00	1.74E+01
2,4-Dintrotoluene	2.72E+00	5.10E+01
Nitrobenzene	3.38E+00	2.43E-01
Pentachloronitrobenzene	8.00E-02	1.71E-01
2,6-Dinitrotoluene	3.15E+00	4.41E+01
*Geometric mean**	*1.65E+00*	*4.39E+00*
*Geometric standard deviation***	*6.95E +00*	*2.44E +02*
Phthalate esters		
Bis (2-ethylhexyl) phthalate	3.80E-02	2.33E+03
Di (n) octyl phthalate	1.57E-04	6.30E+08
*Geometric mean**	*2.44E-03*	*1.21E+06*
*Geometric standard deviation***	*4.56E+00*	*1.17E+03*

* Calculated by using the equation (17) ** Calculated by using the equation (19)

Approach: Similar to the bio-concentration factor for aquatic species, the uncertainty analysis of these parameters can be performed by using the lognormal distribution method (Cullen and Frey, 1999, U.S. EPA, 1999d). The geometric mean and the standard deviation are required for the analysis. Equations 18 and 20 will be used to calculate the errors in terms of standard deviation. The data sources for the plant bio-concentration factor are the Ecotox database (U.S. EPA, 2003) and the MEPAS database (Battelle Memorial Institute, 1997).

1. Retrieve the data from the sources.
2. Gather and transform the data.
3. Calculate the geometric mean using Equation (17) and the standard deviation using the Equation (19).

If there is only one value, this datum will represent the geometric mean where the coefficient of variance (CV) is 1 (McKone, 1993; Currie *et al.*, 1994).
Because the coefficient of variance is the ratio between the standard deviation to the mean value, in this conservative case, the geometric standard deviation will be the same value as the geometric mean. The standard deviation will be propagated into the error of the exposure model. If there is no data available, the estimation method will be used. The estimation methods will be discussed in the following section.

For example, consider mercuric chloride and methyl mercury, which have been reported in laboratory data of the soil to plant bio-concentration factors (U.S. EPA,

1999d). Based on their data, the geometric mean and the standard deviation have been calculated by using the equations (17) and (19). The results are shown in Table 5.16.

5.3.2.2 Estimation Methods for Plant Bio-Concentration Factor. When laboratory data are not available, estimation methods will be used for the soil to plant bio-concentration factors. These methods are discussed in the following subsections.

5.3.2.2.1 Organic Compounds.

In the case of the plant-soil coefficient of root-zone soil to roots (K_{ps1}), McKone (1993) provides an estimation equation as:

$$K_{ps1} = 270 \times K_{ow}^{-0.58} \pm 0.73 \qquad (21)$$

K_{ps1} = Plant-soil partition coefficient for root zone soil to roots,

mg/kg (soil)/mg/kg (roots)

K_{ow} = Octanol-water partition coefficient (L/kg)

For K_{ps2}, the ratio of contaminant concentration in aboveground plant parts (mg/kg plant fresh mass) to contaminant concentration (mg/kg) in dry root-zone soil, McKone (1993) provides the following equation to estimate the value for 29 persistent organochlorides. U.S. EPA (1993b; 1995) used this equation to calculate the bio-concentration factor in aboveground vegetables for organic chemicals when experimental data were not available.

Table 5.16 Soil to Plant Bio-Concentration Factors (mg/kg plant/mg/kg soil), (U.S. EPA, 1999a)

Chemical	Number of data	Range	Geometric Mean*	Standard deviation**
Mercuric chloride	3	0.022-0.075	0.0375	0.0261
Methyl mercury	3	0.062-0.277	0.1368	0.1193

* Calculated by using the equation (17) ** Calculated by using the equation (19)

$$K_{ps2} = 7.7 \times K_{ow}^{-0.58} \pm 0.73 \quad (22)$$

where Kps = plant-soil bio-concentration factor, mg/kg (plant tissue)/mg/kg (soil)

For the root concentration factor (RCF), which used for root vegetables, is representing the ratio of the concentration in roots to the concentration in water. A relationship between RCF and K_{ow} derived by Briggs *et al.* (1982) based on the experimental measurement of chemical uptake by roots is as follows:

$$RCF = 0.82 + 0.03 K_{ow}^{0.77} \pm 0.98 \quad (23)$$

where RCF = root concentration factor, mg/kg (plant tissue)/mg/L (soil water)

Other routes of exposure for vegetation include the direct deposition of particles and the absorption of vapor by plant surfaces (U.S. EPA, 1994a; 1994b; 1995). The K_{pa} represents the ratio of the contaminant concentration in the aboveground plant parts in mg/kg to the contaminant concentration in the air gases and bound to the particles in mg/m^3. Mckone (1993) developed a correlation of the leaf-air bio-concentration factors with the octanol-water partition coefficient. The modified equation to estimate the plant-air partition coefficient is the following:

$$K_{pa} = [0.5 + (0.4 + 0.01K_{ow}) \times \frac{RT}{H}] \times 10^{-3} \pm 0.85 \quad (24)$$

where Kpa = Plant- air partition coefficient for air to above ground plant parts, m^3/kg

R = universal gas constant, 8.314 Pa-m^3/mol/K

T = temperature, K

H = contaminant-specific Henry's law constant, Pa-m^3/mol

Most estimation equations depend on the chemical properties and the octanol/water partitioning coefficient; therefore, the following section will discuss the details of the definition and data sources for this parameter.

5.3.2.2.2 Octanol/Water Partitioning Coefficient.

The octanol/water partitioning coefficient (K_{ow}) is defined as the ratio of the solute concentration in the water-saturated *n*-octanol phase to the solute concentration in the water phase (Montgomery and Welkom, 1991). The octanol/water partitioning coefficient is a widely used parameter for correlating biological effects of organic substances (Lide, 1997). The K_{ow} provides a measure of the lipophilic versus hydrophilic nature of a compound, which is an important consideration in assessing the potential toxicity (Lide, 1997; Mackay *et al.*, 2000). The Kow values were obtained from U.S. EPA (1999a), Mackay *et al.* (2000), MEPAS database (Battelle Memorial Institute, 1997), Lyman *et al.* (1990), Lide (1988), and Yaws (1999).

5.3.2.2.3 Inorganic Compounds.

Bio-concentration factors for inorganic contaminants, B_v, represents the ratio of contaminant concentration in above ground plant part to contaminant concentration in soil. If data are not available, the estimation method developed by Hope (1995) will be used to calculate B_v.

$$\text{Log } B_v = 2.791 - 0.564 \log S \pm 1.99 \qquad (25)$$

where B_v = Bio-concentration factor for vegetative plant parts, mg/kg (plant)/mg/kg (soil) and S = Water solubility (mg/L)

5.4 Contaminant Concentrations

In the ERA model, the contaminant concentrations represent the values based on their media: soil, water, and air. The lognormal distribution is applicable to contaminant concentrations from surface water, which was already discussed in Chapter 4. In addition, this section will provide more details regarding the statistical goodness of fit test.

To demonstrate that a lognormal distribution fits to the contaminant concentrations in the environment, the data sets of uranium and chromium concentrations in soil from APG and YPG sites were used (Ebinger *et al.*, 1996). The data sets are shown in Tables 5.17 and 5.18.

To determine whether the lognormal distribution is an adequate descriptor of the data set, statistical goodness of fit tests, the Shapiro-Wilk, *W,* test and the Anderson-Darling, *A*, test were used as test methods. The Shapiro-Wilk, *W,* test is a statistical goodness of fit test that performs well on small sample sizes (<50) and tests the null hypothesis that the data values are random samples from a normal distribution against an unspecified alternative distribution (McBean and Rovers, 1998). The test is considered one of the best numerical tests of normality (Gilbert, 1987). Details of the Shapiro-Wilk test were already discussed in Chapter 4

The Anderson-Darling, *A*, test is used to test if a sample of data came from a population with a specific distribution. It is a modification of the Kolmogorov-Smirnov (*K-S*) test and gives more weight to the tails than does the K-S test (Cullen and Frey, 1999). The Anderson-Darling test makes use of the specific distribution in calculating critical values.

Table 5.17 Uranium Concentrations in Soil at APG and YPG (Ebinger *et al.*, 1996)

No. of Samples	Uranium concentration in soil (mg/kg)	
	APG	YPG
1	17.28	220.6
2	2.7	43.22
3	5.94	110.42
4	86.4	140.6
5	9.18	21.05
6	7.29	43.22
7	5.13	602.6
8	11.07	822.8
9	1.19	55.26
10	0.95	21.15
11	4.05	1205.6
12	0.84	1404.2
13	0.81	24.12
14	0.54	41.27
15	0.27	2.7
16	7.56	0.21
17	5.4	25.04
18	0.27	13.47
19	1.81	26.94
20	0.27	38.11
21	1	0.0025
22	0.19	100.44
23	1.11	
24	0.3	
25	2.19	
26	0.49	
27	0.54	
28	0.27	
29	2.7	
30	0.38	
31	1.4	
32	0.65	
33	0.43	
34	0.35	
35	2.19	

Table 5.18 Chromium (VI) Concentrations in Sediment at YPG, mg/kg (U.S Army YPG, 1999)

B1	B3	GP	IA	B2	B4
5.6	5.6	6.3	6.9	2.8	3.8
6.9	6.5	6.4	7	4.3	4.8
6.9	6.5	7	8.2	4.5	4.9
7.1	6.8	7.3	8.3	5.2	5.3
7.1	6.8	7.3	8.4	5.3	5.4
7.2	7	7.3	8.5	5.4	5.4
7.3	7.1	7.3	8.6	5.5	5.4
7.4	7.1	7.4	8.7	5.7	5.5
7.6	7.3	7.5	9	5.8	5.5
7.7	7.5	7.6	9	5.9	5.5
7.7	7.6	7.7	9.2	6.1	5.7
7.8	7.6	7.8	9.4	6.2	5.8
7.8	7.9	7.8	11	6.4	5.9
7.8	7.9	8.1	13	6.4	6
7.9	8.7			6.5	6.2
7.9	8.8			6.6	6.3
8.7	9.1			6.6	6.4
	9.5				6.4
	11				6.4
	12				6.6

Location map: Appendix D

IA - Impact L field (Figure D-3)

GP- Gun Position, 24,500J (Figure D-4)

B1- Upstream of GP Impact area (Figure D-5)

B2-Downstream for GP impact area (Figure D-6)

B3-Upstream for extend HE impact area long (Figure D-7)

B4-Downstream for extended HE impact area long (Figure D-8)

For evaluating the fit of a distribution, the Anderson-Darling test is performed as follows: (a) arrange the data in ascending order; (b) calculate standardized values of the data; (c) calculate the cumulative probability for the fitted distribution; (d) calculate the Anderson-Darling statistics; (e) compute a modified statistic, A^*, and (f) compare the modified statistic to the critical value to decide whether to reject the hypothesis that the data are described by the hypothesized distribution.

The Anderson-Darling statistic, A^2 is calculated from the following equation (Linnet, 1988):

$$A^2 = -N - \frac{1}{N}\left\{\sum_{i=1}^{N}(2i-1)[\ln z_i + \ln(1 - z_{N+1-i}]\right\} \tag{26}$$

where

N = number of samples

z = the value of the cumulative probability function for the i^{th} variable

The Anderson-Darling statistic is then modified based on the sample size for comparison with the critical value:

$$A^* = A^2\left(1.0 + \frac{0.75}{N} + \frac{2.25}{N^2}\right) \tag{27}$$

The modified value, A^*, is then compared with a critical value. The critical value depends on the desired significance level. The values of A^* are 0.6, 0.8, 0.9, 1.0, and 1.2 for the significance levels of 0.01, 0.05, 0.025, 0.01, and 0.005, respectively (Cullen and Frey, 1999; Linnet, 1988, Stephens, 1974)

The results of the goodness of fit test are shown in Table 5.19. From the results, the W value of the lognormal distribution function at the APG site is higher than the W

Table 5.19 Goodness of Fit Test Results

Location	Shapiro Wilk, *W*-Test[a]		Anderson-Darling , *A*-Test[b]	
	Normal	**Lognormal**	**Normal**	**Lognormal**
APG				
Uranium	0.4(0.9)	0.9(*0.9*)	8.2(*1.2*)	0.6(*1.2*)
YPG				
Uranium	0.6(0.8)	0.8(*0.8*)	4.1 (*1.2*)	1.2(*1.2*)
Chromium			0.9(*1.2*)	0.7(*1.2*)

[a]:reject the null hypothesis if an estimated value is lower than a critical value (Gilbert, 1987)

[b]: reject the null hypothesis if an estimated value is greater than a critical value (Cullen and Frey, 1999)

*( ) = critical value at significance level of 0.01

critical value. This indicates that the lognormal distribution is fit to describe the character of uranium contaminants at the APG site. The Anderson-Darling test results also showed that the log-transformed data is well within the critical values of the statistic (Cullen and Frey, 1999).

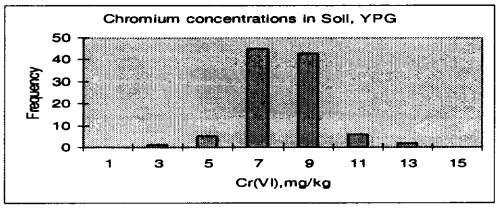
For YPG, both chromium and uranium concentrations in the soil are in agreement regarding the Anderson-Darling-*A* goodness of fit test. With 102 values of chromium concentrations (U.S. Army YPG, 1998), the estimated *A* - value for lognormal distributions is 0.73. The critical value at the significance level of 0.01 is 1.2 (Linnet, 1988; Stephens, 1974). Therefore, the test result showed that a lognormal distribution is reasonable to use since the test value is less than the critical value (Cullen and Frey, 1999). There is no Shapiro-Wilk, *W*-test for chromium since this method is limited to sample sizes less than 50.

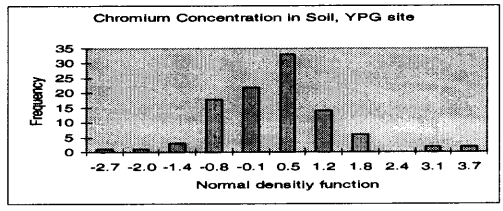
The goodness of fit test results (Shapiro-Wilk, *W*-test and Anderson-Darling, *A* test) revealed that the estimated *W*-value of DU at YPG (0.8) is not lesser than the critical value (0.8) at the significance level 0.01. With the *W*-test result, we cannot reject the hypothesis that the data set of log-transformed data is not normally distributed (McBean and Rovers, 1998). The result is consistent with the *A* test in which the estimated *A* value was not greater than the *A* critical value. From the results of the goodness of fit tests for both chromium (YPG) and DU concentrations (APG and YPG), the lognormal distribution is reasonable to represent the contaminant concentration in media at both sites.

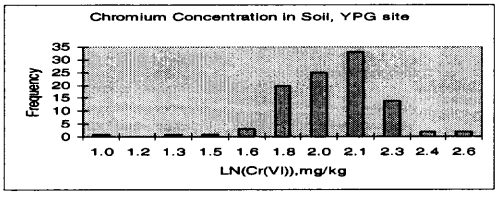
According to NPRP (1996), one of the criteria for selecting a type of distribution is that the form of the distribution should reflect the magnitude, range, and interpretation

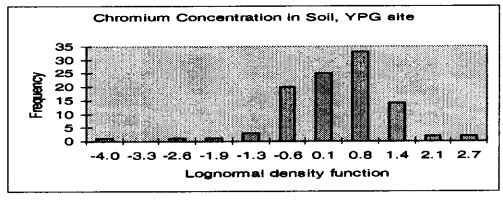
of the parameter. For example, a contaminant concentration cannot be a negative value; therefore, the sampling distribution should reflect the restricted range, with no chance of randomly drawing a negative value. The selected distribution must represent the range of the possible values of the parameter at the specific sites. As Warren-Hicks *et al.* (2002) mentioned; the selected distribution should be consistent between sites for specific parameters. Since there is evidence from the results of the goodness of fit tests that a lognormal distribution is appropriate to use for uranium concentrations in the APG site, therefore this distribution should be assumed to describe the uranium concentration in the YPG site as well. Furthermore, when plotting the histogram of data sets between the normal distribution function and the lognormal distribution function, the histograms of normal distribution function tend to be right-skewed, and the histograms of the lognormal distribution function tend to be bell curved (Figure 5.11). These results reveal that logarithms of chromium and uranium concentration data are approximately normally distributed (Peretz *et al.*, 1997; NIOSH, 1977).

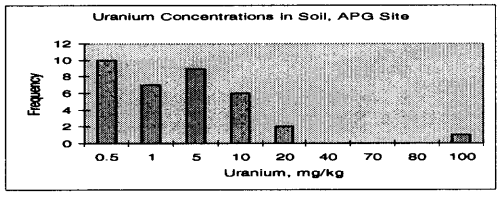
Approach: Similar to the bio-concentration factor for aquatic species, the uncertainty analysis of the contaminant concentration can be performed by using the lognormal distribution (Cullen and Frey, 1999, U.S. EPA, 1999d). The geometric mean and the standard deviation are required for an analysis. Equations (18) - (20) will be used to calculate the errors in terms of standard deviation. Using laboratory data, the following steps will be conducted in the uncertainty analysis of the contaminant concentration.

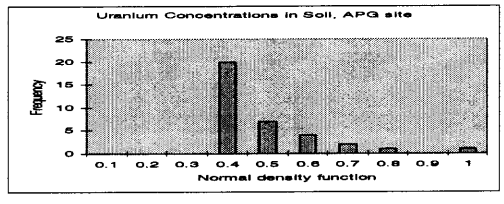


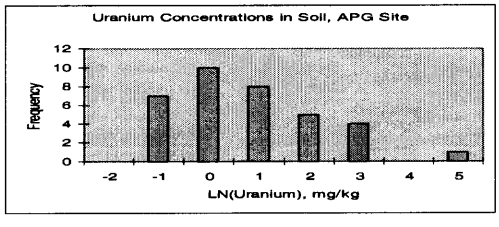


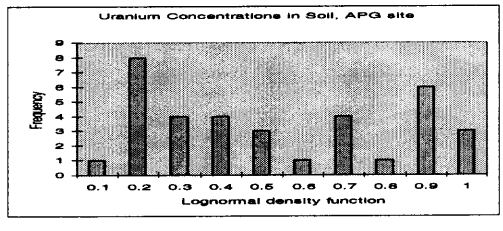


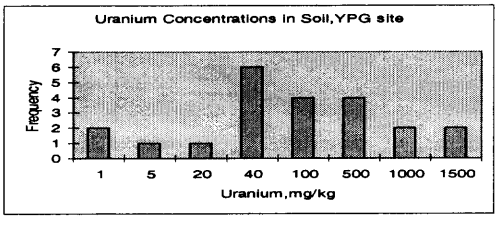


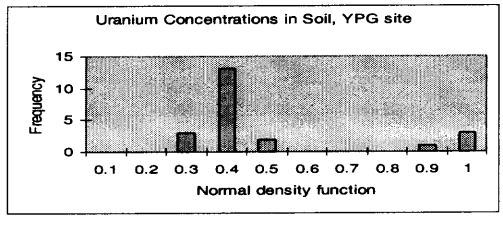


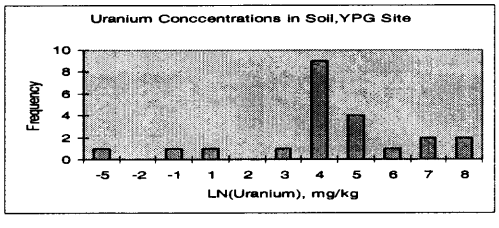












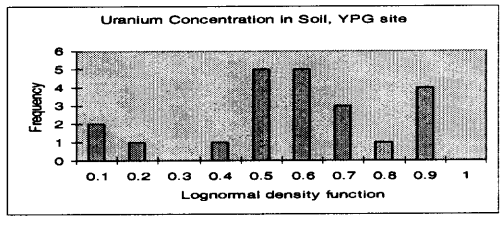


Figure 5.11 Normal and Lognormal Distributions at APG and YPG.

1. Retrieve the data from the laboratory.
2. Gather and transform the data.
3. Calculate the geometric mean and standard deviation using the Equation (11) and Equation (13), respectively.

When only one value exists, this will be used as the geometric mean and the coefficient of variance (CV) is 1 (McKone, 1993; Currie *et al.*, 1994). Because the coefficient of variance is the ratio between the standard deviation to the mean value, in this conservative case, the geometric standard deviation will be the same value as the geometric mean. The standard deviation will be propagated into the error of the exposure model.

5.5 Summary

The range of body weight is varied depending on the type of receptors. The mean value represents the average weight of adults, but the range covers both juveniles and adults. For this reason, the lower bound and upper bound are quite different for each receptor. For ingestion rates (both food and water), inhalation rates, and surface area, all are dependent on body weight (as their equation is a function of body weight). Therefore, the range of these parameters is similar to the body weight range. The standard deviation of these parameters represents the error. If standard deviation is unknown, the estimation method may be applied which is based on knowing the range value. For the soil contact fraction, the site use factor, and the seasonal factor, as there are limited data available, the default values will be used for these parameters. The default value of 1 will be used for

both site use factor and seasonal factor. For soil contact fraction, the value of 0.22 will be used for terrestrial arthropods, mammals, and birds. The contaminant specific dermal absorption factor for terrestrial animals, also has limited data. Therefore, the trend of this factor cannot be described in terms of a parameter range. Similar to the mass fraction of soil/sediment in the diet and the weight fraction of food item in receptor diet, the value of this factor is more specific depending on receptors. The default values are used for these parameters, too.

For the bio-concentration factors for aquatic species and terrestrial plants, the geometric mean and the standard deviation of each aquatic animal and plant parameter are required to perform an uncertainty analysis. The ECOTOX database is one of the many important sources that provide peer reviewed data from various laboratories. The estimation methods will be used when data are not available.

The contaminant concentration also has uncertainty, which will be addressed using the lognormal distribution. Since the contaminant concentration in the environment appears to follow a skewed probability, the lognormal distribution is an appropriate tool to analyze the uncertainty of this parameter. Table 5.20 provides the final approach for each parameter.

Model parameters were well characterized in this chapter. Next chapter will focus on the parameter sensitivity analysis. Model verification and model validation are also concerned in this study.

Table 5.20 Inputs for Animals, Plants and Aquatic Species Exposure Models

Parameter	Definition	Unit	Distribution/Value	Data Required	References
EC	Contaminant concentration	mg/L (water), mg/kg (soil), mg/m^3 (air)	lognormal	geometric mean, standard deviation	6,7,13,15,17,18,20,21 ,22,25,28
BW	Body weight	kg	normal	mean, standard deviation	3,7,10,12,13,23,27,28
IR_f	Food ingestion rate	kg/day	normal	mean, standard deviation	3,12,13,23
IR_{dw}	Ingestion rate of drinking water	L/day	normal	mean, standard devia4tion	12,13,23
IR_i	Inhalation rate	M^3/day	normal	mean, standard deviation	7,23
SA	Surface area	cm^2	normal	mean, standard deviation	13,23
AF	Soil-to-skin adherence factor	mg/ cm^2	default value	-	9,24
α_d	Contaminant-specific dermal absorption factor	mg/kg (body burden) / mg/kg (daily dose)	default value	-	9,24
P_{cs}	Fraction of receptor surface area in contact with soil per day	d^{-1}	default value	-	9,10,24
θ	Site use factor	ratio of contaminant area to home range	default value	-	9,10
ψ	Seasonal factor	fraction of time per year receptor occurs at site	default value	-	9,10
FS	Mass fraction of soil or sediment in the diet	%of diet (dry weight basis)	default value	-	9
FR_{fk}	Weight fraction of food item in receptor diet	kg (food)/kg (diet)	default value	-	9
BCF	bio-concentration factor	L/kg	lognormal	geometric mean, standard deviation	8,10,11,13,14,16,26

Table 5.20 Inputs for Animals, Plants and Aquatic Species Exposure Models (continued)

Parameter	Definition	Unit	Distribution	Data Required	References
K_{ps1}	Plant-soil partition coefficient for root-zone soil to roots	mg/kg (soil)/mg/kg (roots)	lognormal	geometric mean, standard deviation	1,4,8,9,14,15,24
K_{pa}	Plant-air partition coefficient for air to above-ground plant parts	m^3 /kg	lognormal	geometric mean, standard deviation	2,8,9,14,15,19
RCF	Root concentration factor	L/kg	lognormal	geometric mean, standard deviation	1,4,9,14,24
B_v, K_{ps2}	Bio-concentration factor for vegetative plant parts	mg/kg (soil)/mg/kg (vegetative plant)	lognormal	geometric mean, standard deviation	1,4,9,14,15,24
B_r	Bio-concentration factor for non-vegetative plant parts	mg/kg (soil)/mg/kg (vegetative plant)	lognormal	geometric mean, standard deviation	1,4,9,14,15,24

References:

1. Absallom *et al.*, (1999)
2. Bacci *et al.*, (1990)
3. Briggs *et al.*, (1983)
4. Finley *et al.*, (1994)
5. Greenland, (2001)
6. Hattis *et al.*, (2001),
7. Hertwich *et al.* (1999)
8. Hope (1995)
9. Hope (1999)
10. Kenaga and Goring (1980)
11. Lahkim *et al.* (1999)
12. MacIntosh *et al.* (1994)
13. McKone (1993)
14. McKone (1994)
15. Moore *et al.* (1999)
16. Nayak *et al.* (2001)
17. Ott, (1990)
18. Polder *et al.* (1998)
19. Rai and Krewski (1998)
20. Smith (1994)
21. Stow and Qian (1998)
22. Travis and Arms (1988)
23. U.S. EPA (1993a)
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26. West and Kodell (1999)
27. Wiwatanadate and Claycamp(2000)

CHAPTER 6

PARAMETER SENSITIVITY ANALYSIS AND MODEL VERIFICATION

Based on the methods and approach discussed in Chapters 3 and 4, the code was modified to develop a computationally efficient method for uncertainty propagation. The Monte Carlo Sampling method is applicable to a wide range of ecological risk assessment models associated with uncertainty propagation as already discussed in Chapter 2. In the past, a computational model may not have been feasible due to computer capability and time limitations. Nowadays, the capacity of computers can overcome these limitations. The ease in which a method can be used is an important factor in model applicability. The use of Visual Basic offers an alternative technique to develop a user-friendly probabilistic simulation tool. Microsoft Excel is also useful and easily used to calculate the descriptive statistics and probabilistic distributions. Therefore, to accomplish this work, the parameter sensitivity analysis and model verification were studied.

6.1 Parameter Sensitivity Analysis

Due to the large amount of parameters used in ERA models, it is advisable to identify those with the largest impact on the model results. For this reason sensitivity analysis is carried out. Parameter sensitivity analysis is a tool that describes the significance of each parameter in the model. To determine the sensitivity of parameters within the model, one parameter will be varied at random, while the remaining parameters are held at fixed values. Sensitivity analysis is the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model output (Saltelli, 2002).

Subsequently, sensitivity is calculated by computing correlation coefficients between every assumption and every parameter. A correlation coefficient is a measure of the degree of association or covariance between two random variables (Cullen and Frey, 1999). Correlation coefficients provide an estimate of the linear dependence of a model output on a particular model input. Sample correlation coefficients are sensitive to two factors: (1) the strength of a linear relationship between the input and output, and (2) the range of variation of the output relative to the range of variation of the input. A positive correlation coefficient means that as the values of one variable increase (or decrease) so too does the value of the other variable. The stronger the relationship, the closer the value is to 1 or 100 %.

Correlation coefficient is estimated based on the sample values of the inputs and output, their respective means (Cullen and Frey, 1999).

$$\rho_{x,y} = \frac{\sum_{k=1}^{m}\left(x_k - \bar{x}\right)\left(y_k - \bar{y}\right)}{\left(\sum_{k=1}^{m}\left(x_k - \bar{x}\right)^2 \sum_{k=1}^{m}\left(y_k - \bar{y}\right)^2\right)^{1/2}} \tag{28}$$

When m is the sample size (number of iterations in the simulation), x is an input, y is an output, and x_k and y_k are sample values of x and y. The value of the correlation, $\rho_{x,y}$, may vary from –1 to 1.

$\rho_{x,y}$ = 1 implies linear dependence, positive slope (y increases as x increases),

$\rho_{x,y}$ = 0 implies no linear dependence, thus the value of x provides no useful information about the value of y, and

$\rho_{x,y}$ = -1 implies linear dependence, negative slope (y decreases as x increases).

Correlation greater than 0.5 indicate substantial dependence of the output the input. Larger correlation coefficients indicate less dispersion of sample values from an idealized linear relationship between an input and an output. Therefore, the correlation coefficient has been investigated. Results from this study are shown in Tables E-1 to E-4, Appendix E.

A high sensitivity indicates a strong dependence on the parameter; a low sensitivity indicates a weak dependence. The sensitivity of the results with respect to specified parameters can finally be obtained in the term of correlation coefficients. For terrestrial animal, especially ingestion pathways; four parameters strongly influence the EHQ or risk estimate values, which include contaminant concentration, food ingestion rate, water ingestion rate, body weight. For dermal exposure, contaminant concentration in soil and the surface area is also sensitive to the EHQ value, which is in agreement with the model hypothesis.

The capability of ERA to perform a sensitivity analysis is based on the design characteristics of a computer program. Accurate sensitivity analysis results can then be used to establish priorities for the input data collection.

6.2 Model Verification

Verification refers to the task or procedure by which a mathematical solution to an arbitrarily complex problem is tested for internal mathematical consistency and accuracy. ERA model calculation results were verified by hand calculations. These hand calculations required the use of a computer spreadsheet (Microsoft Excel). Two receptors were selected: white-tailed deer and American kestrel. A White-tailed deer represents a

herbivore while an American kestrel represents a carnivore within the ecosystem. Uranium was selected to represent the chemical contaminant to be analyzed. A range of uranium concentrations in different media (1-1000 mg/L for surface water; 1-1000 mg/kg for soil; 1-1000 mg/m^3 for air) was selected to assess exposure to terrestrial receptors. Mallard, white-footed mouse, terrestrial arthropods, periphyton and rushes represented a body burden concentration in the food web. Three pathways were considered: ingestion, inhalation and dermal absorption.

Ingestion of contaminant is the most significant route of exposure in assessing risks to terrestrial animals. In terms of both frequency and magnitude, for receptors above the primary producer trophic level, ingestion can include both secondary exposure (contaminated forage or prey is consumed), and primary exposure (contaminated water, sediments, or soil are consumed). The associated equations are:

$$ADD_i = [(EC_s \times FS \times IR_i) / BW] \times \theta \times \psi \quad (29)$$

$$ADD_i = [(EC_w \times IR_{iw})/BW] \times \theta \times \psi \quad (30)$$

$$ADD_i = \sum (C_k \times FR_{fk} \times IR_i/BW) \times \theta \times \psi \quad (31)$$

where EC_i = contaminant concentration in medium (mg/kg for soil EC_s, mg/L for water EC_w, and mg/ m^3 for air EC_a)

C_k = contaminant concentration in receptor from the k^{th} pathway (mg/kg)

FS = mass fraction of soil or sediment in the diet (as percentage of diet on dry weight basis)

IR_i = ingestion rate on dry-weight basis (kg/day)

IR_{iw} = ingestion rate of drinking water (mg/day)

FR_{fk} = wet weight fraction of the k^{th} food item in receptor diet (kg food/kg diet)

BW = body weight of receptor (kg)

θ = site use factor

ψ = seasonality factor; percentage of time per year receptor dwells at site

For the total applied daily dose per terrestrial animal via ingestion exposure pathways:

$$ADD_{ingestion} = \Sigma\, ADD_i \qquad (32)$$

where $ADD_{ingestion}$ = applied daily dose through all the concerned exposure pathways (dermal absorption, ingestion and inhalation) (mg contaminant/kg of receptor body weight)

Dermal exposure could be a significant exposure route for animals that are in frequent contact with contaminated water, sediment, or soil. The following model is used to estimate exposure based on an approximation of the mass of soil or sediment adhering to an area of an animal's skin surface.

$$ADD_i = [(SA \times AF \times P_{cs} \times EC_s \times CF \times \alpha_i)/BW] \times \theta \times \psi \qquad (33)$$

Where ADD_i = applied daily dose to the receptor through the i^{th} exposure pathway (mg contaminant/kg of receptor body weight)

SA = surface area of ecological receptor (cm^2)

AF = soil-to-skin adherence factor (mg/cm^2)

P_{cs} = fraction of receptor surface area in contact with soil per day (d^{-1})

α_i = contaminant-specific absorption factor (mg/kg contaminant body burden / mg/kg absorbed daily dose)

CF = conversion factor (1×10^{-6} kg/mg)

Exposure via inhalation of volatilized contaminants and fugitive dust is evaluated with the following equation (U.S. EPA, 1993):

$$ADD_i = [(IR_a \times EC_a)/BW] \times \theta \times \psi \quad (34)$$

where IR_a = inhalation rate (m^3/day)

To apply a complex food web, the trophic levels are considered and evaluated through the relational DBMS to express predator-prey food relationships in the model. Summary input parameters are provided in Table 6.1. The results are provided in Table 6.2.

Ingestion, inhalation, and dermal absorption exposure pathways represent the principal means by which terrestrial wildlife receptors are exposed to contamination. These receptors may receive exposure through direct contact (primary pathway) with abiotic media and/or consumption (secondary pathway) of contaminated food. Exposure estimation for these species must, therefore, include consideration of contaminant body burdens in the lower trophic level. Because using a food web model requires ecological information with respect to historical data and site-specific feeding relationships, the process introduces a crucial ecological perspective into what might otherwise be a purely toxicological exercise (Hope, 1995).

Table 6.1 Parameter Inputs for Model Verification

Parameter	Definition	White-tailed deer	American kestrel	Mallard	White foot mouse	Arthropods (insect)
AF	Soil to skin adherence factor	1.45	1.45	1.45	1.45	1.45
Br	Bioconcentration factor for vegetative plant parts	0.0002	0.0002	0.0002	0.0002	0.0002
Bv	Bioconcentration factor for non-vegetative plant parts	0.0002	0.0002	0.0002	0.0002	0.0002
BW	Body weight	80.9	0.123	1.134	0.0222	0.0015
Ke	Depuration rate	0.125	0.125	0.125	0.125	0.125
Faplant	Weight fraction of food item(aquatic plant)	0	0	0.25	0	0
Fbird	Weight fraction of food item(bird)	0	0.46	0	0	0
Fdermal	Dermal absorption factor	0.01	0.01	0.01	0.01	0.01
Fingestion	Ingestion absorption factor	0.05	0.05	0.05	0.05	0.05
Finhalation	Inhalation absorption factor	0.05	0.05	0.05	0.05	0.05
Finsect	Weight fraction of food item(insect)	0		0	0.02	0
Ftanimal	Weight fraction of food item(terrestrial animal)	0	0.54	0	0	0
Ftplant	Weight fraction of food item(terrestrial plant)	1	0	0.75	0.98	1

Table 6.1 Parameter Inputs for Model Verification (Continued)

Parameter	Definition	White-tailed deer	American kestrel	Mallard	White foot mouse	Arthropods (insect)
FS	Mass fraction of soil in the diet	0.02	0.02	0.033 0.000006	0.02	0.01
Ifw	Ingestion rate of water	5.16	0.0145	4	0.003	0
Irf	Ingestion rate of food	8.7	0.015	0.00063	0.01	0.000003
Iri	Inhalation rate	36.68	0.163	0.9	0.05	0.000099
Pc	Fraction of surface area in contact with soil	0.22	0.25	0.25	0.22	0.25
Q	Site use factor	1	1	1	1	1
SA	Surface area	19057.75	247.72	1090	92.26	0.0002
W	Seasonal factor	1	1	1	1	1

Table 6.2 Comparisons the ERA Model and Spreadsheet Results

White-tailed deer						
Concentration	**ADDingestion**		**ADDinhalation**		**ADDdermal absorption**	
(ECi)	Model	Spreadsheet	Model	Spreadsheet	Model	Spreadsheet
1	0.07	0.07	0.45	0.45	7.51E-07	7.51E-07
10	0.66	0.66	4.53	4.53	7.51E-06	7.51E-06
100	6.63	6.60	45.34	45.34	7.51E-05	7.51E-05
1000	66.30	65.98	453.39	453.40	7.51E-04	7.51E-04

American kestrel						
Concentration	**ADDingestion**		**ADDinhalation**		**ADDdermal absorption**	
(ECi)	Model	Spreadsheet	Model	Spreadsheet	Model	Spreadsheet
1	0.20	0.20	1.32	1.32	7.30E-06	7.30E-06
10	2.03	2.03	13.24	13.25	7.30E-05	7.30E-05
100	20.31	20.27	132.42	132.52	7.30E-04	7.30E-04
1000	203.07	202.71	1324.25	1325.20	7.30E-03	7.30E-03

The ERA code is written in Visual Basic and integrated into the software by linking it with a Windows-based interface and the DBMS. The developed ERA software was subsequently verified. From the results for white-tailed deer and American kestrel, the ERA model predicted ADD values in agreement with the spreadsheet calculated ADD values. Moreover, the results demonstrated that as a contaminant concentration in an ERA model predicted ADD values in agreement with the spreadsheet calculated ADD values. Moreover, the results demonstrated that as a contaminant concentration in a medium increases, the body burden or applied daily dose increases. Therefore, as the media concentration increases, the risk on the ecosystem rises as would be expected given the associated algorithms.

6.3 Summary

Parameter sensitivity analysis can be obtained in the term of correlation coefficients. Results revealed that four parameters strongly influence the EHQ or risk estimate values for terrestrial animal, especially ingestion pathways; which include contaminant concentration, food ingestion rate, water ingestion rate, body weight. Therefore, sensitivity analysis results can then be used to establish priorities for the input data collection.

Model verification is a tested for internal mathematical consistency and accuracy. ERA model calculation results were verified by hand calculations. These hand calculations required the use of a computer spreadsheet (Microsoft Excel). From the results for white-tailed deer and American kestrel, the ERA model predicted ADD values in agreement with the spreadsheet calculated ADD values. Moreover, the results

demonstrated that as a contaminant concentration in a medium increases, the body burden or applied daily dose increases. Therefore, as the media concentration increases, the risk on the ecosystem rises as would be expected given the associated algorithms.

Results from model verification revealed the accuracy and precision of the ERA model prediction; therefore, the case study was performed to access the risk estimates at APG and YPG. More details will be discussed in the next chapter.

CHAPTER 7

DEMONSTRATION OF RISK EVALUATION

Yuma and Aberdeen Proving Grounds were selected as baseline ecosystems for the case study representing an arid desert system and a coastal environment, respectively. Terrestrial and aquatic plant and animal receptors and site characteristics were assembled based on guidelines for conducting an ecological risk assessment (U.S. EPA, 1998a). The most important routes of exposure at YPG are root uptake for terrestrial plants and ingestion, inhalation, and dermal absorption for the terrestrial animals. All potential routes of exposure are considered for terrestrial and aquatic species at APG, which includes root uptake for terrestrial plants; ingestion, inhalation, and dermal absorption for terrestrial animals; and direct contact for aquatic species. Two case studies are presented. The first on depleted uranium (DU) is of importance because DU penetrators are employed at both firing ranges. In the second case study of evaluating the effect on replacing chromium electroplated gun barrels with sputtered tantalum, hexavalent chromium and tantalum concentrations in the media must be defined based on use, release, storage, and transport of the processed gun barrels. Other than tantalum, molybdenum is also another alternative coating to replace chromium and is evaluated in this study.

In this Chapter, the case studies are implemented with the software. The input data are discussed, which includes the rationale for selected contaminant concentrations. Risk characterization is conducted for the case study examining the two ecosystems, and results are analyzed.

7.1 Risk Assessment for DU

Depleted uranium is a by-product from processing natural uranium to produce the enriched form used as fuel for nuclear reactors or military applications (Hartmann *et al.*, 2000). Health risk of exposure to DU is a complex issue. Because of the low specific radioactivity and the dominance of α-radiation, no acute risk is likely from external exposure (Bleise *et al.*, 2003). However, internalized DU has a greater potential for adverse impacts on body than that from externalized exposure, such as mutagenesis from radiological effects where risks are a function of the particle characteristics. Chemical impacts, renal, reproductive, and developmental, are a function of the route of exposure, duration of exposure, and speciation (Fulco *et al.*, 2000). McClain *et al.* (2001) studied the primary transport route of DU through wounds and confirmed mutagenic behavior of DU, which transformed human osteoblast cells to a tumorigenic phenotype. The non-radioactive (or chemical effect) associated with exposure to uranium and its compounds involves renal toxicity, detected by the presence of protein and cell casts in the urine. Additionally, the chemical and radiological impacts of uranium can act synergistically to cause tissue damage. Therefore, it cannot be assumed that cancer is due solely to the radiological effects of uranium or that organ damage is exclusively due to its heavy-metal properties (Fulco *et al.*, 2000).

Since the 1950s, DU has been used as a penetrator in munitions and testing programs at APG, which is located in the western shore of Chesapeake Bay, a productive and complex ecosystem. The facility provides design and testing of ordnance material in close proximity to the nation's industrial and shipping centers. As a result of the program, DU has been deposited on over 1500 acres. Most penetrator impacts occur within about

500 m of the firing axis after the DU munitions pass through soft targets used to check accuracy and performance. Penetrators strike the ground, trees, and wetlands after hitting soft targets and eventually come to rest in the impact area (Ebinger *et al.*, 1996). A second-highly used test area is located at YPG near the Arizona-California border and in the vicinity of the Colorado River, Squaw Lake, and Mittry Lake. YPG began testing DU munitions against soft targets in the 1980s, and the test area comprises 12,000 acres (Oxenberg, 1997). Ebinger *et al.* (1996) reported that redistribution in the arid environment at YPG was mainly due to erosion of DU fragments and redeposition in washes that drain the area. Ingestion of DU by wildlife is likely from consuming DU-contaminated soil accumulated on vegetation or pelts.

Concerns have been raised at these two sites about the risk posed to associated ecosystems due to potential exposure to DU. In this study, the ERA simulation tool was employed to assess risk associated with exposure to depleted uranium (DU) at two U.S. Army sites, APG and YPG.

7.1.1 Risk Characterization

Once the ecosystem and site characteristics are fully understood, the applied daily dose (ADD) or body burden can be estimated for an individual receptor. An ecological hazard quotient (EHQ) is then calculated by dividing the $ADD_{pathway}$ (or body burden) by the reference value:

$$EHQ = ADD_{pathway} \div reference\ \ value \tag{35}$$

The reference value recommended in this model is the no observed adverse effect level (NOAEL) or no observed adverse effect concentration (NOAEC) for terrestrial and

aquatic species, respectively. The NOAEL and NOAEC are derived from experiments conducted on laboratory species, and represent the highest dose or contaminant concentration applied that did not result in a measurable adverse effect in the 95% of potential population (Cockerham and Shane, 1994; Sample *et al.*, 1998; Weiss, 1999). For example, uranium reference values for terrestrial animals represent doses that did not adversely affect the receptor's reproductive system; for terrestrial plants the exceedance of benchmark represents potential reduction in the plant's root weight at a 20% level of effects. The reference values for aquatic species are the highest doses that did not increase mortality at a 20% level of effects (Sample *et al.*, 1998).

Based on the selected reference values, the EHQ represents varying levels of risk or measures of levels of concern (Tannenbaum *et al.*, 2003). Although risk categories are outlined here, receptor risk should be evaluated individually based on the endpoint. An EHQ less than 1 suggests the toxicological effects are potentially unlikely to occur and hence the possibility for unacceptable risk is minimal (Tannenbaum *et al.*, 2003). A NOAEL-based EHQ greater than 1 but less than the LOAEL (lowest observed adverse effect level) may indicate that effects are possible but uncertain. Finally a LOAEL-based EHQ>1 indicates that effects are probable and exposure exceeded the lowest dose associated with effects. The EHQ value provides a potential indication of the level of risk to a receptor.

In the risk assessment, as discussed previously, uncertainties are an inherent part because the data and understanding of an ecosystem may be limited. Therefore, probability density functions were sampled using Monte Carlo simulations. By applying the simulation, distribution characteristics were studied and convergence revealed a

minimum iteration of 500 based on the 95th confidence level, which is in agreement with Tellinghuisen (2000). However, in this study, the selected iteration is based on a 99th confidence level, as we are interested in the lower probability outcomes at the tails of the distributions. In this case, 1000 iterations were selected (Frey and Rhodes, 1998).

Probabilistic distributions have been used as a tool to qualify uncertainty in prediction of risks to humans and ecological receptors (Frey and Rhodes, 1998). The distributions characterize the degree of belief that the true but unknown value of a parameter lies within a specified range of values for that parameter (Warren-Hicks *et al.*, 2002). Criteria for selecting a distribution are based on National Council on Radiation Protection and Measurements (NCRP, 1996) and U.S. EPA (1998) guidelines and are further discussed in Chapter 3. The distribution should represent site-specific uncertainty and variation in that parameter (Schumacher *et al.*, 2001). Also, the distribution must represent the range of values for that parameter in a given system. The selected distribution should be consistent between sites for specific parameters (Warren-Hicks *et al.*, 2002). Moreover, the form of the distribution should reflect the magnitude, range, and interpretation of the parameter (NCRP, 1996). For example, contaminant concentration cannot be negative; therefore, the sampling distribution should reflect the restricted range. The probabilistic distributions of the exposure parameters were gathered from a number of studies and are summarized in Table 5.20. As the lognormal distribution has a longer tail than other distributions, it is widely used in environmental analysis to represent positively valued data exhibiting positive skewness (NCRP, 1999; Cullen and Frey, 1999). Pollutant concentration tends to be lognormal distributed, which has been explained by the theory of successive random dilutions (Ott, 1990). After the pollutants

are emitted by the source, they undergo successive mixing and dilution, resulting in a lognormal frequency distribution. Furthermore, a goodness of fit test was conducted to assess the appropriateness of the lognormal distribution for sampling data at both APG and YPG sites. By using a non-parametric Anderson-Darling (A) test, the lognormal distribution was found to be the most appropriate for example for the DU data. Therefore, in this study, the lognormal distribution is selected to represent the distribution form for concentrations in the media. Both aquatic species bio-concentration factors and soil to plant uptake factors are defined as the ratio of contaminant concentration at equilibrium in tissues to that in the water or soil where values were generated from field and/or laboratory data (Jorgensen *et al.*, 1991; PNNL, 1998; Sample *et al.*, 1998). The associated distributions have been observed as skewed, which has led to the use of the logarithmic transformation of the parameter to obtain the lognormal distribution (Traas *et al*, 1996; Verhaar *et al.*, 1999; Samsoe-Petersen *et al.*, 2002; Liao *et al.*, 2003).

Physiological parameters such as body weight, surface area, and ingestion and inhalation rates in terrestrial animals may vary seasonally, geographically, and by age. These parameters typically follow a Gaussian distribution (U.S. EPA, 1993a and 1997b). The normal distribution is commonly used to represent uncertainty resulting from unbiased measurement errors (Morgan and Henrion, 1998). Because the normally distributed random variable takes on values over the entire range of real data, we focus upon the variatoin by calculation the standard deviation. Surface area, ingestion, and inhalation rates are a function of the body weight and are often estimated using allometric equations (U.S. EPA, 1993a).

With limited field or laboratory data, single values are recommended (Hope, 1995 and 1999), the U.S. EPA applied such an approach for soil to skin adherence factors and the contaminant specific dermal absorption factor (U.S. EPA, 1989; U.S. EPA, 1993a; U.S. EPA, 2001). Moreover, because of limited data, these values were based on exposure for humans not terrestrial animals to which they were applied (U.S. EPA, 1989; Hope, 1995). Therefore, in this study, a similar approach was used for parameters related to dermal contact: soil to skin adherence factor, contaminant specific dermal absorption factor, soil contact fraction factor, and site use factor.

7.2 DU Risk Assessment

Once an ecosystem is defined along with the food web, the process for conducting the DU risk assessment included selecting reference values, obtaining concentrations in media, identifying exposure parameters, and validating model results. Among them, exposure parameters have been discussed previously (Chapter 5); in the following, reference value selection, DU concentrations in media, and model and validation results are presented.

7.2.1 Reference Values

The relevant NOAEL and NOAEC data were identified from multiple sources for the terrestrial and aquatic receptors for the two sites (Sample *et al.*, 1996; Efroymson *et al.*, 1997; U.S. EPA, 2003). In instances where toxicological data for receptors were unavailable, surrogate species were selected based on taxonomy, life style, and/or toxicological response similarity. Surrogate application requires applying a conversion

method based on test species and the receptor's body weights. Wildlife NOAELs can be estimated for an untested species by the following equation (Sample and Arenal, 1999):

$$NOAEL_{wildlife} = NOAEL_{test}\left(\frac{bw_{test}}{bw_{wildlife}}\right)^{1-b} \quad (36)$$

Where the $NOAEL_{wildlife}$ represents the ecosystem receptor of concern, the $NOAEL_{test}$ is the surrogate test species for which the *NOAEL* is available, *bw* represents their respective body weights, and *b* is an allometric scaling factor. From Sample and Arenal (1999), scaling factors of 1.2 and 0.94 should be used for birds and mammals, respectively. NOAEL data on test species, mouse and black duck were used to calculate other untested species NOAEL values based on Equation (36). Toxicological data are presented in Tables 7.1-7.3.

7.2.2 DU Concentrations in Media

As discussed previously, the lognormal distribution was applied to describe DU concentrations in both water and soil for APG and YPG. Sampling data on uranium concentrations in surface water, groundwater, and soils from APG and YPG were collected by Ebinger *et al.* (1996) and stored in a database developed and maintained by Los Alamos National Laboratory (Ebinger, 2002). At APG, uranium concentrations in surface and ground water samples were analyzed based on nine samples near the western shore of Chesapeake Bay. Potentially impacted soils were sampled mainly in conjunction with well water sampling and were collected over 1,500 acres; a total of 35 samples were collected representing an extremely limited data set (Table 7.4). The sampling areas are shown in Figures 7.1-7.2.

Table 7.1 Uranium Toxicological Data for Terrestrial Wildlife

Analyte	Form[a]	Test Species	Test NOAEL[b] (mg/kg/d)	Endpoint	Estimated NOAEL[c, d] (mg/kg/d)
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	Little Brown Bat	3.322
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	Short-tailed Shrew	3.187
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	White-footed Mouse	3.115
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	Meadow Vole	2.988
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	Mink	2.477
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	Cottontail Rabbit	2.45
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	Red Fox	2.263
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	River Otter	2.187
$UO_2(CH_2COOH)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	mouse	3.07	White-tail Deer	1.945
$U_{(s)}$	$DU_{(s)}$	black duck	16	American Robin	9.163
$U_{(s)}$	$DU_{(s)}$	black duck	16	Belted Kingfisher	10.442
$U_{(s)}$	$DU_{(s)}$	black duck	16	American Woodcock	11.068
$U_{(s)}$	$DU_{(s)}$	black duck	16	Cooper's Hawk	12.979
$U_{(s)}$	$DU_{(s)}$	black duck	16	Barn Owl	13.135
$U_{(s)}$	$DU_{(s)}$	black duck	16	Barred Owl	14.317
$U_{(s)}$	$DU_{(s)}$	black duck	16	Red-tailed Hawk	15.669
$U_{(s)}$	$DU_{(s)}$	black duck	16	Osprey	16.594
$U_{(s)}$	$DU_{(s)}$	black duck	16	Great Blue Heron	18.215

[a] pH: 6-7, the percent of $UO_2CO_{3(AQ)}$: $UO_2(OH)^+$ is 45:55

[b] Sample *et al.*, 1996.

[c] b= 0.94 mammals and 1.2 birds

[d] NOAEL: 0.9 (mg/kg/d) (for Lizards (side-blotched), Western aquatic garter snake, Woodhouse's toad (adult))

Table 7.2 Uranium Toxicological Data for Terrestrial Plants

Analyte	Form[a]	Test Species[b]	Test LOEC (mg/kg)	Endpoint
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Swiss chard	5	Fern
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Swiss chard	5	Rushes
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Swiss chard	5	Slender blue flag
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Swiss chard	5	Creosote bush,
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Swiss chard	5	Foothill paloverde trees
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Swiss chard	5	Saguaro cactus

[a] pH: 6-7 , the percent of $UO_2CO_{3(AQ)}$: $UO_2(OH)^+$ is 45:55

[b] Efroymson *et al.*,1997.

Table 7.3 Uranium Toxicological Data for Aquatic Species

Analyte	Form[a]	Species	Test NOAEC[b] (mg/L)	Aquatic species
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Periphyton	2	Aquatic plants[c]
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Phytoplankton	2	
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Water milfoil	2	
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Mountain whitefish	0.021	Aquatic animals[d]
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Pacific lamprey	0.021	
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	Rainbow trout (adults)	0.021	
		Rainbow trout (edds)		
		Rainbow trout (larvae)		
$UO_2(NO_3)_2$	$UO_2CO_{3(AQ)}$ $UO_2(OH)^+$	White sturgeon	0.021	

[a] pH 6-7, , the percent of $UO_2CO_{3(AQ)}$: $UO_2(OH)^+$ is 45:55
[b] Ecological Toxicity Database (U.S EPA,2003).
[c] Surrogate aquatic plants are Chlorella vulgaris and Green algae.
[d] Surrogate aquatic animals are Fathead minnow.

Table 7.4 Uranium Concentrations in Media at YPG and APG (Adapted from Ebinger *et al.*, 1996)

Sample No.	YPG	APG	
	in soil (mg/kg)	in soil (mg/kg)	in water (µg/L)
1	220.6	17.28	0.17
2	43.22	2.7	0.99
3	110.42	5.94	0.51
4	140.6	86.4	0.03
5	21.05	9.18	0.19
6	43.22	7.29	0.99
7	602.6	5.13	0.96
8	822.8	11.07	10.30
9	55.26	1.19	1.01
10	21.15	0.95	
11	1205.6	4.05	
12	1404.2	0.84	
13	24.12	0.81	
14	41.27	0.54	
15	2.7	0.27	
16	0.21	7.56	
17	25.04	5.4	
18	13.47	0.27	
19	26.94	1.81	
20	38.11	0.27	
21	0.0025	1.0	
22	100.44	0.19	
23		1.11	
24		0.3	
25		2.19	
26		0.49	
27		0.54	
28		0.27	
29		2.7	
30		0.38	
31		1.4	
32		0.65	
33		0.43	
34		0.35	
35		2.19	

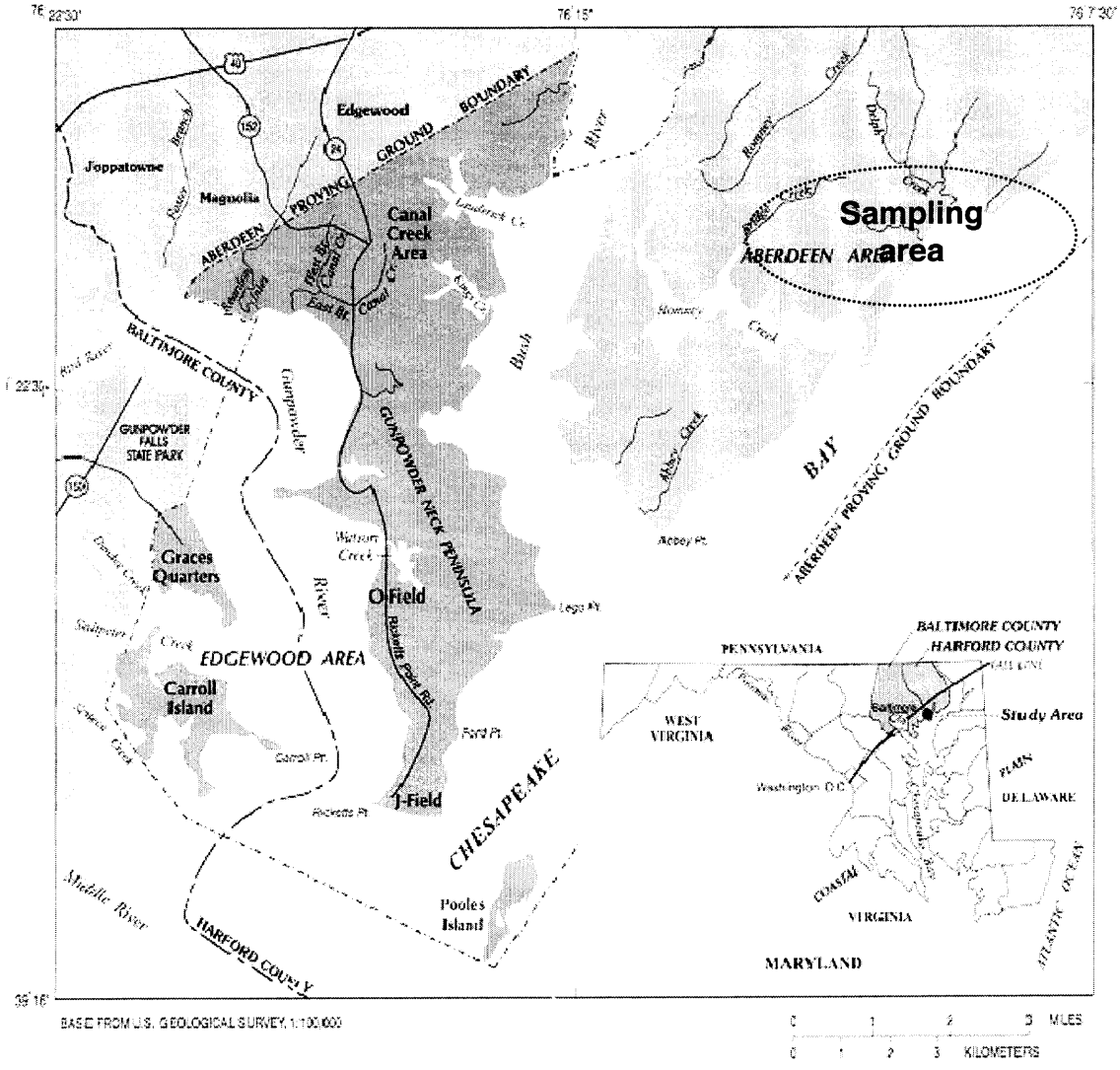


Figure 7.1 DU Sampling Areas, APG, Maryland (Adapted from Donnelly *et al.*, 1998).

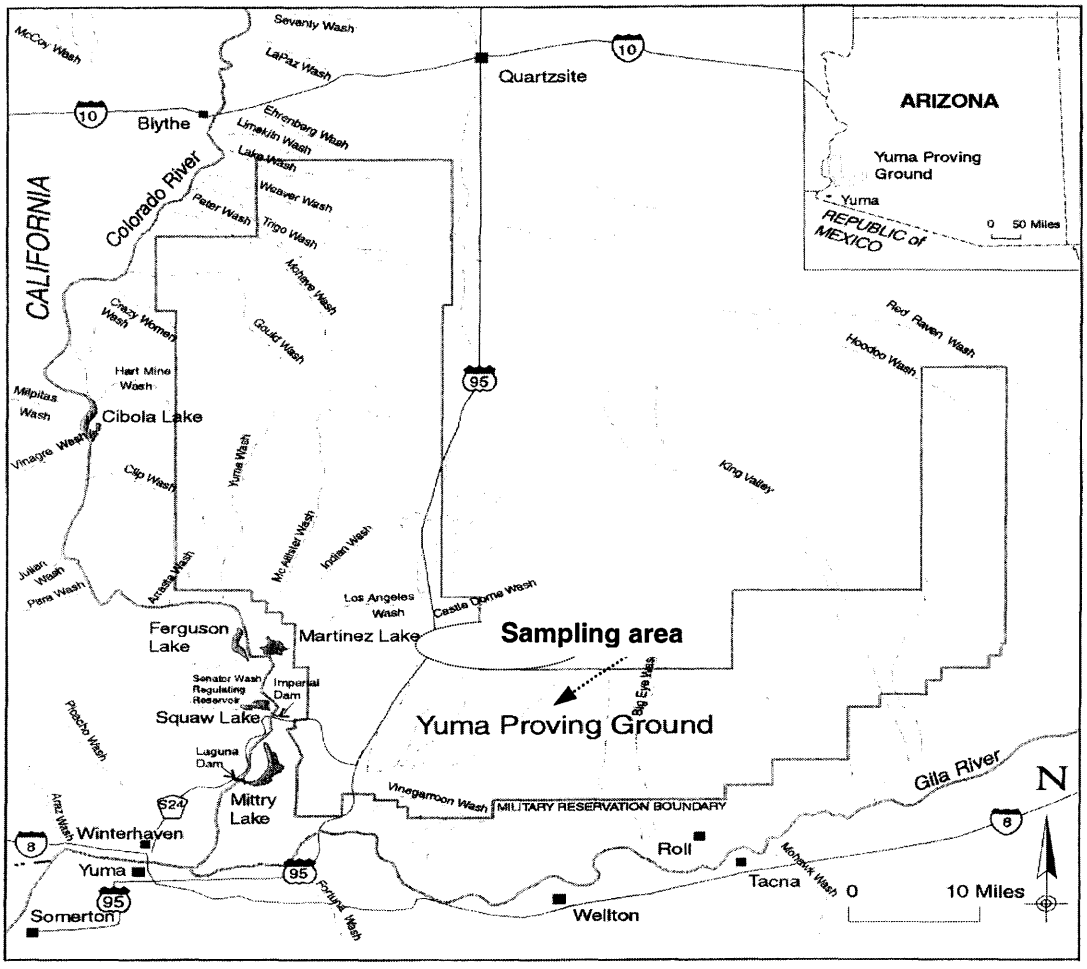


Figure 7.2 DU Sampling Areas, YPG, Arizona (Adapted from Entech Engineers, 1988).

YPG is characterized as a typical desert ecosystem; therefore field studies were conducted, for the most part, on soil samples. Ebinger *et al.* (1996) established sample plots on two firing ranges at YPG. Plots were distributed nonrandomly along the area of 12,000 acres, where first penetrator impacts were closely clustered and had been identified as exhibiting elevated levels of DU contamination (Price, 1991; Ebinger *et al.*, 1996; Oxenberg, 1997). These areas were situated along the axis of the firing line and could be identified by impact craters, recently displaced soils, and DU fragments. Locations for sample plots varied along the firing line and from observable impact craters and according to Ebinger *et al.* (1996) were assumed to cover a range of contaminant levels for each firing line. According to U.S. EPA's soil sampling protocol (U.S. EPA, 1992c), when a plume is suspected and the orientation of the plume can be estimated, the sampling grid should be oriented in such a manner that the extending axis of the grid is parallel to the suspected plume center line; however, this is not necessary and a square or rectangular grid is one of the most useful for reconnaissance. DU concentrations in soil were based on 22 samples, again a very limited data set for the impacted area.

7.2.3 Risks Results

Based on speciation, $UO_2CO_3^0{}_{(AQ)}$ and $UO_2(OH)^+$ are the two dominant and mobile species at pH 6-7 and pE 5-15 that may adversely affect receptors from exposure. For YPG terrestrial plants (Figure 7.3), because of high DU concentrations in soil, the overall distributions for DU uptake for the creosote bush, foothill paloverde trees, and saguaro cactus suggest a 90% likelihood in reduction in root weight. For most terrestrial animals at YPG, given DU concentrations in soil, the dose is less than that resulting in a decrease

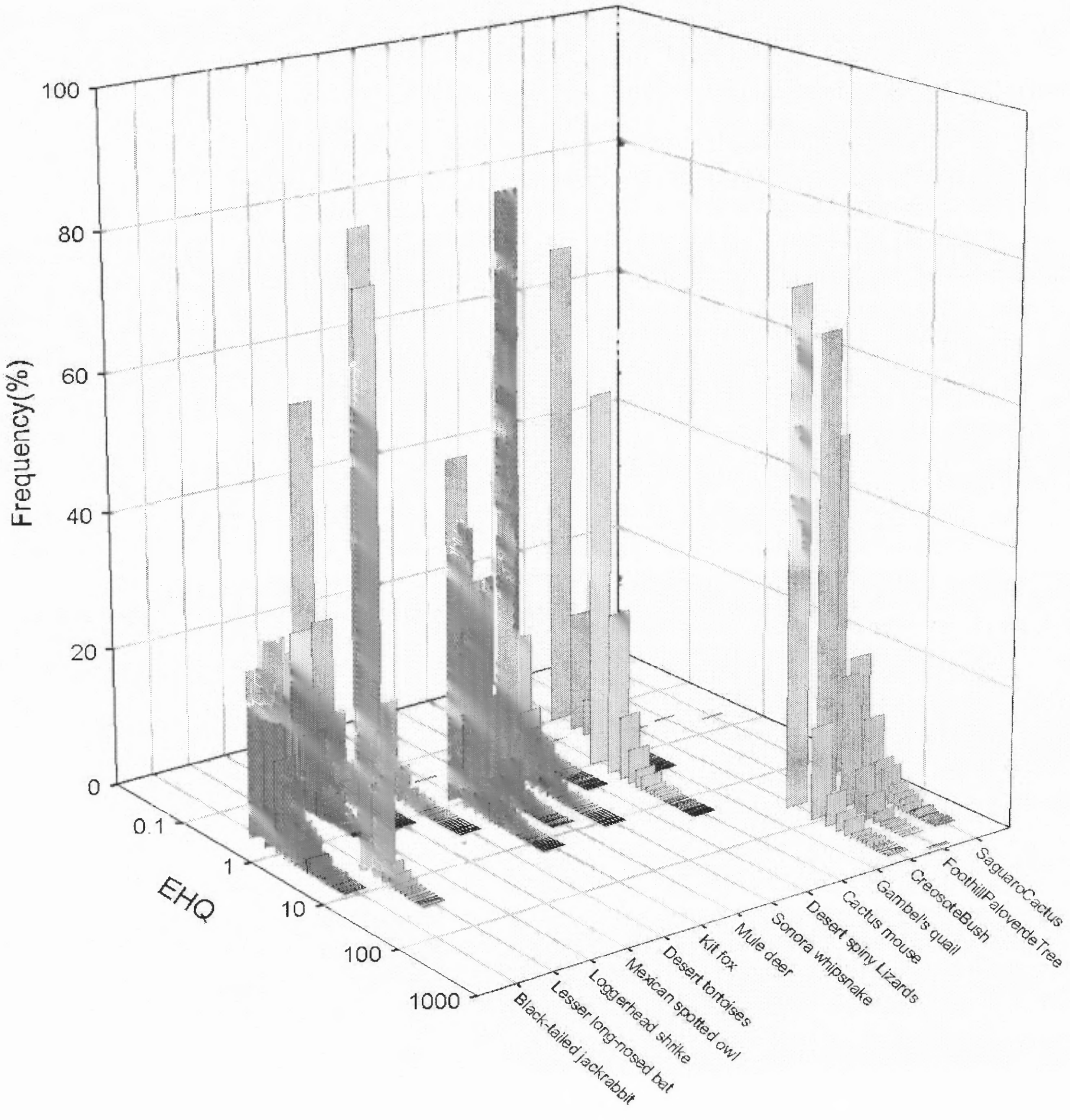


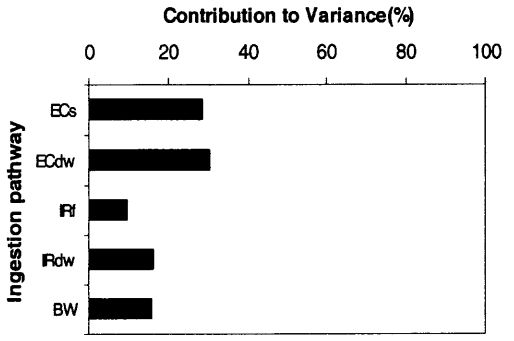
Figure 7.3 EHQ Distributions for YPG Terrestrial Receptors.

in offspring. However, for the lesser long-nosed bat, reproduction effects are expected to occur through the reduction in size and weight of offspring.

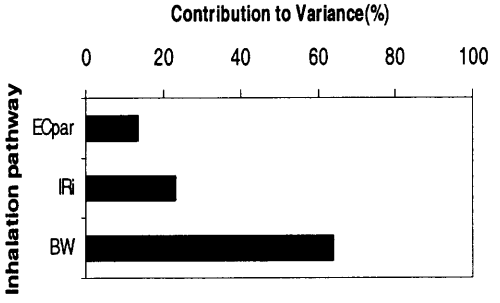
To indicate which input parameters most strongly influence the final exposure estimate, a sensitivity analysis is performed with the lesser longnosed bat. The ingestion pathway is the most critical (Figure 7.4) where four parameters strongly influence the risk distribution: contaminant concentration, food ingestion rate, water ingestion rate, and body weight. For dermal exposure, contaminant concentration in soil and the surface area exposed also affect the risk distribution.

Among the different exposure pathways for the bat, including ingestion, inhalation, and dermal absorption, the dominant pathway is through insect ingestion, which accounts for 97% of its diet. Furthermore, insect exposure includes all the concerned ingestion pathways -- soil, water, and food (plants) as well as dermal and inhalation exposure. Based on terrestrial animals' characteristics and their responses to DU exposure, the bat is more vulnerable than other terrestrial species. The positive skewness of risk distribution for the bat exemplifies this sensitivity (Figure 7.5).

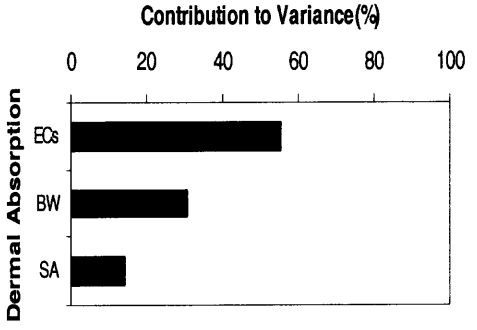
From field studies (Ebinger *et al.*, 1996), pocket mice, kangaroo rat, and white-throated woodrat samples were analyzed for uranium concentrations to estimate risk levels at YPG (Figure 7.6). Samples of carcasses, kidneys, and livers from these animals were collected for identifying uranium concentrations. For pocket mice, the greatest uranium concentration was found in carcass samples, 115.4 mg kg^{-1}; for the kangaroo rat, the worst case was observed in kidney samples 4.3 mg kg^{-1}; and for the white-throated woodrat, the greatest concentration of uranium was 76.7 mg kg^{-1} in carcass samples.



Parameter	Definition
Ecs	Contaminant concentration in soil/sediment
Ecdw	Contaminant concentration in drinking water supply
Irf	Food ingestion rate
Irdw	Water ingestion rate
BW	Body weight

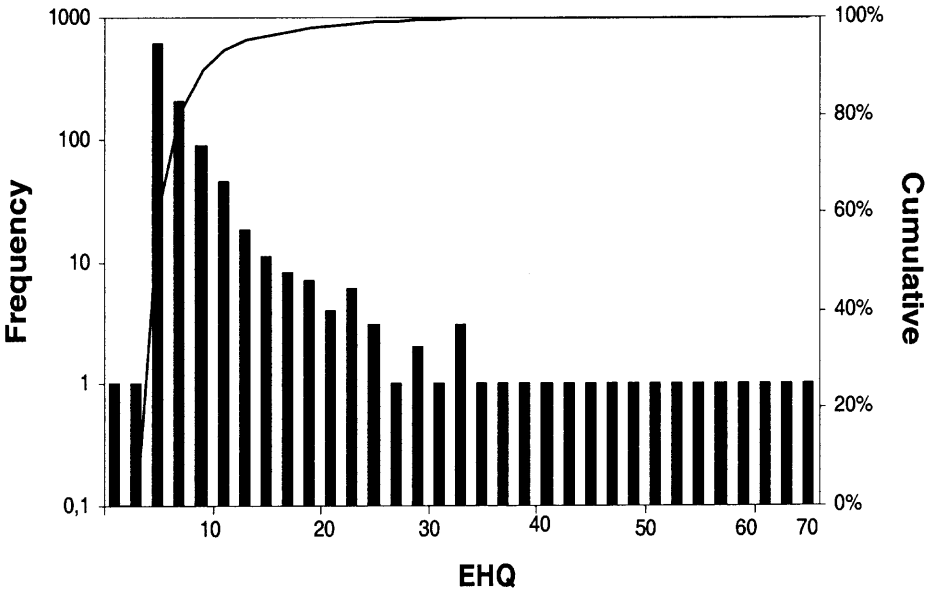


Parameter	Definition
ECpar	Concentration of particulate-bound contaminant in air
IRi	Inhalation rate
BW	Body weight



Parameter	Definition
ECs	Contaminant concentration in soil/sediment
BW	Body weight
SA	Surface area

Figure 7.4 Parameter Sensitivity Analysis, Lesser Longnosed Bat, YPG.



Statistical data	
Mean	3.86E+00
Standard Error	1.08E-01
Median	3.05E+00
Standard Deviation	3.41E+00
Sample Variance	1.16E+01
Kurtosis	1.68E+02
Skewness	1.07E+01
Range	6.77E+01
Minimum	2.18E+00
Maximum	6.99E+01
Sum	3.86E+03
Count	1.00E+03
Confidence Level(95.0%)	2.11E-01

Figure 7.5 Statistical Data for EHQ (Lesser Long-Nosed Bat).

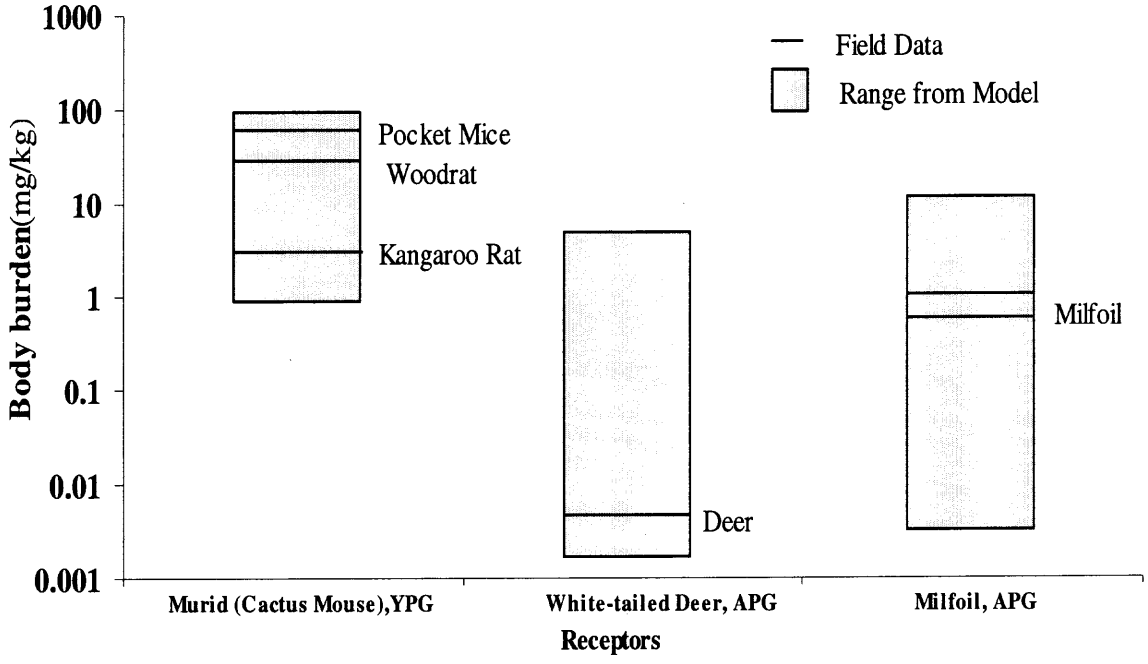
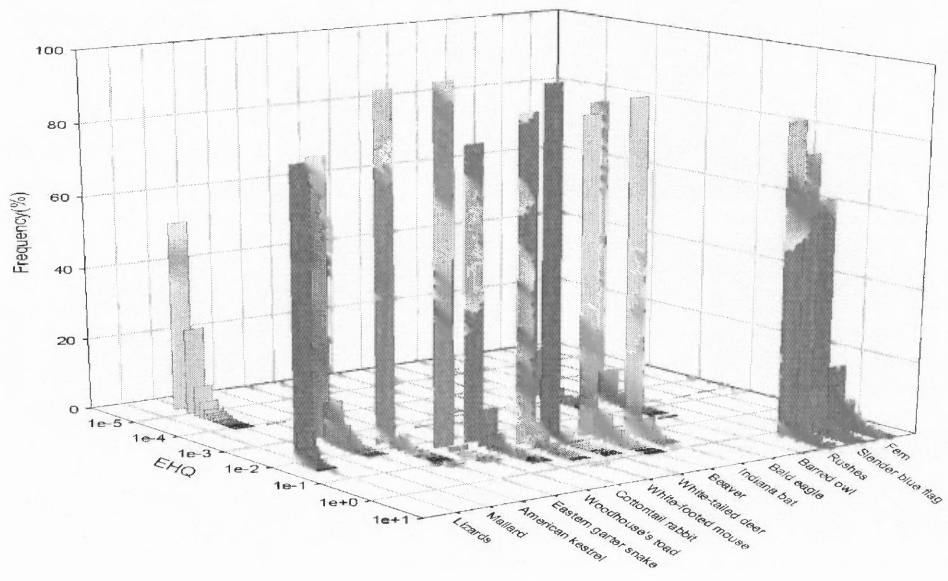


Figure 7.6 ERA ModelingValidation on DU at YPG and APG.

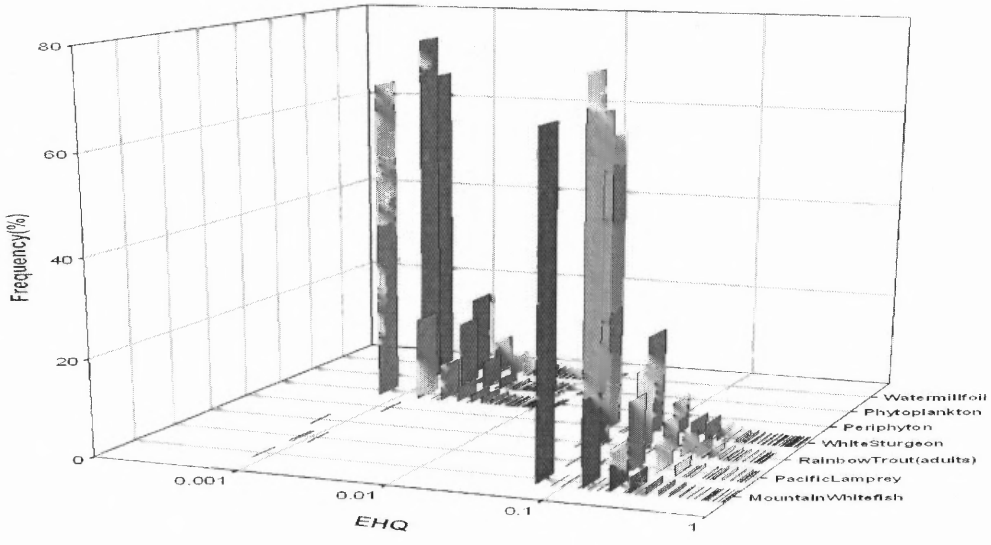
Based on our risk assessment, a receptor from the same family, Murid cactus mouse, exhibited a uranium concentration of 2.46 to 224.6 mg kg^{-1}. Sampling data from Murid receptors, pocket mice, kangaroo rat, and white-throated woodrat, fall into the distribution predicted in the ERA tool

At APG, again based on limited DU data, exposure potentially poses little risk for terrestrial animals (Figure 7.7), representing the likelihood that there is no observable impact on receptor's reproduction or development. Ebinger *et al.* (1996) collected deer samples to evaluate potential DU uptake and transfer to humans who consume deer. They analyzed kidney, livers, muscle, and bone samples, and found that the greatest uranium concentration among those samples was 0.0051 mg kg^{-1}, which falls in the distribution observed in this stimulation of 0.0042 to 7.3 $mg.kg^{-1}$ for white-tailed deer. For APG terrestrial plants, modeling results of risk showed that for rushes, slender blue flag, and fern, there is a 90 % likelihood of a reduction in root weight.

Compared with terrestrial plants at APG, uranium potentially poses lower risks to aquatic plants and again this is based on a very limited set of data (Figure 7.7). Considering DU exposure to aquatic animals at APG, uranium uptake is potentially not expected to increase mortality. For the aquatic plant, milfoil, two samples were collected (Ebinger *et al.,* 1996) from field studies, where 2.1 and 0.8 mg kg^{-1} of uranium were observed. Our modeling results show that the uranium concentration in milfoil ranged from 6.4×10^{-3} to 18.6 mg kg^{-1}, and are consistent with field data (Figure 7.6). Ebinger *et al.* (1996) also observed DU penetrator impacts through isotopic ratios measured in cattail and pickerel weed, representing



a) EHQ distributions for terrestrial receptors



b) EHQ distributions for aquatic receptors

Figure 7.7 EHQ Distributions for APG Receptors.

uptake, attachment, or adsorption of DU from water or sediments where these aquatic organisms grow.

7.2.4 Summary

Risks from exposure to DU at two U.S Army sites, APG and YPG, were characterized based on the data available. Exposure pathways for terrestrial and aquatic plants and animals were applied in software developed using Visual Basic 6.0 with associated parameters stored in the Microsoft Access DBMS. To characterize risk and address uncertainty, the model employs Monte Carlo simulations for assessing parameter and risks as probabilistic distributions. Results from the ERA model suggest that at YPG, a reduction in plant root weight is considered likely to occur from exposure to uranium. For most terrestrial animals at YPG, the predicted DU dose is less than that resulting in a decrease in offspring. However, for the lesser long-nosed bat, reproductive effects are expected to occur in the reduction in size and weight of offspring. At APG, uranium uptake may not likely affect survival of aquatic plants and animals.

However, data were limited reflecting the risk observed and further field investigations at both sites are recommended. Through model validation, the results from the ERA model are consistent with sampling data from field studies of Ebinger *et al.* (1996).

7.3 Comparative Analysis of Risk for Chromium, Tantalum, and Molybdenum

In this section, the ERA model implementation for chromium, tantalum, and molybdenum assessment at APG and YPG is discussed. The modeling is based on work of Lu (2001), Fan *et al.* (2001), and the U.S. Army YPG (1999). Potential exposure of the

ecosystem to gun coatings such as chromium can have a significant adverse impact on the receptors. Tantalum and molybdenum are other alternative coating being considered to replace chromium. Therefore, the potential risks associated with chromium, tantalum, and molybdenum for APG and YPG were studied.

The contaminant concentrations for chromium are based on soil and air sampling data conducted at the YPG site (U.S. Army YPG, 1999). Equivalent concentrations of the alternative metal coatings Ta and Mo have been applied based on the assumption that test firing continues at the same rate and the loss of a replacement metal is equivalent to that of the chromium. For APG, no data were available. However, as YPG has a greater gun barrel testing capability and longer testing history than APG, and considering a worst-case scenario, the concentrations observed at YPG have been applied to the APG site. The contaminant concentration in surface water at APG was estimated using soil-water distribution coefficients based on the contaminant concentration in the soil at YPG (Lu, 2001).

Reference value selection was consistent with that discussed in Section 7.2.1. The relative NOAEL and NOAEC data were identified from multiple sources for the terrestrial and aquatic receptors of the case study (ECOTOX, 2003; Efroymson *et al.*, 1997; PNNL, 1998; Sample *et al.*, 1996). Again, where data for a particular receptor were unavailable, surrogates were selected based on taxonomy, life style, and/or toxicological response similarity. The surrogates selected in the case study are shown in Table 7.5. The reference values for the case study are shown in Tables 7.6 to 7.8. Likewise, when chemical information is lacking, other surrogates are used.

Table 7.5 Surrogates and Receptors for APG and YPG

Sites Receptor		Surrogates[a]	Contaminants[b]
APG	Beaver	River otter	Cr_2O_3 $CrK(SO_4)_2$,K_2CrO_4, Cr^{+6}, MoO_4, $MoNa_2O_4$, $NaVO_3$, VSO_4
	Indiana bat	Little brown bat	
	Mallard, American kestrel, Barred owl, Bald eagle	Black duck	$CrK(SO_4)_2$
		Chicken	MoO_4
		Mallard duck	VSO_4
	Fern, rush, Slender blue flag	Lettuce, Oats, Tomato, Swiss chard	$K_2Cr_2O_7$,Mo, V,
	Periphyton, phytoplankton, Water millfoil	Algae and phytoplankton	CrK_2O_7
		Dinoflagellate	Mo, V
	Mountain whitefish, Pacific lamprey, White sturgeon	Rainbow trout, Carp	CrO_3
		Fathead minnow,	MoO_3, V_2O_5,
YPG	Black tailed rabbit	Cottontail rabbit	Cr_2O_3, $CrK(SO_4)_2$, K_2CrO_4, Cr^{+6}, MoO_4, $MoNa_2O_4$,$NaVO_3$ VSO_4,
	Cactus mouse, Kit fox	White-footed mouse Red fox	
	Mexican spotted owl, Loggerhead shrike, Gamble's quail	Black Duck	$CrK(SO_4)_2$,
		Chicken	MoO_4
		Mallard duck	VSO_4
	Creosote bush, Foothill paloverde trees, Saguaro cactus	Lettuce, Oats, Tomato, Swiss chard	$K_2Cr_2O_7$, Mo, VSO_4

[a]: Sample *et al.* (1996); PNNL (1998).

[b]: Vanadium applied as surrogates for tantalum

Table 7.6 Terrestrial Plant Receptors and NOAELs[a]

Terrestrial Plant	Chromium[a] (VI) (mg/kg/day)	Molybdenum (mg/kg/day)	Vanadium[b] (mg/kg/day)
Fern	1.8	2.0	2.5
Rushes	6.8	2.0	2.5
Slender blue flag	7.4	2.0	2.5
Creosote bush	11.0	2.0	2.5
Foothill paloverde trees	31.0	2.0	2.5
Saguaro cactus	21.0	2.0	2.5

[a]: Analyte tested was $K_2Cr_2O_7$.

[b]: Vanadium applied as a surrogate for tantalum and the effect of $VOSO_4$ on germination and radical length after 3 days of growth in solution of radish, cabbage, turnip, lettuce, wheat, and millet (Sample *et al.*,1998)

Table 7.7 Terrestrial Animal Receptors and NOAELs

Terrestrial Animal	**Chromium (VI) (K_2CrO_4) (mg/kg/day)**	**Molybdenum (MoO_4, $MoNa_2O_4$) (mg/kg/day)**	**Vanadium[a] (VSO_4 ,$NaVO_3$) (mg/kg/day)**
Eastern garter snake[b]	0.133	3.53	11.4
Lizards	0.133	3.53	11.4
Woodhouse's toad	0.133	3.53	11.4
Beaver	1.5	0.06	0.089
White-tailed deer	0.92	0.04	0.055
Cactus mouse	6.55	0.28	0.389
White-footed mouse	6.55	0.28	0.389
Mallard	0.133	3.53	11.4
Bald eagle	0.133	3.53	11.4
American kestrel	0.133	3.53	11.4
Cottontail rabbit	2.41	0.1	0.143
Black-tailed jackrabbit	2.41	0.1	0.143
Indiana bat	8.57	0.37	0.51
Lesser long-nosed bat	8.57	0.37	0.51
Kit fox	1.73	0.07	0.103
Gambel's quail	0.133	3.53	11.4
Loggerhead shrike	0.133	3.53	11.4
Barred owl	0.133	3.53	11.4
Mexican spotted owl	0.133	3.53	11.4
Sonora whipsnake	0.133	3.53	11.4
Desert tortoises	0.133	3.53	11.4
Desert spiny Lizards	0.133	3.53	11.4

[a]: Vanadium applied as a surrogate for tantalum.

[b]: For reptiles and amphibians (eastern garter snake, lizards, woodhouse's toad, Sonora whipsnake, desert tortoises and desert spiny Lizards), NOAELs are derived from LOAELs (PNNL, 1998).

Table 7.8 Aquatic Animal and Plant Receptors and NOAECs [a]

Aquatic Animal	Chromium (VI) (CrO_3) (µg/L/day)	Molybdenun (MoO_3) (µg/L/day)	Vanadium (V_2O_5) (µg/L/day)	Tantalum[b] (µg/L/day)
Mountain whitefish	1.2	4190	1.13	1.13
Pacific lamprey, juvenile	1.2	4190	1.13	1.13
Rainbow trout: adult, eggs, larvae	1.2	4190	1.07	28.9
White sturgeon (common, mirror, colored, carp)	65.3	4190	1.13	1.13
Periphyton	2.3	30	12	12
Phytoplankton	2.3	30	12	12
Water millfoil	23	30	12	12

[a]: ECOTOX (2003).

[b]: For Mountain whitefish, pacific lamprey and white sturgeon, vanadium was applied as a surrogate for tantalum; for rainbow trout, data available for Ta_2O_5.

A literature survey revealed that neither NOAELs nor LOAELs have been established for any tantalum compounds. However, because vanadium and tantalum are within the same group on the Periodic Table, they possess similar physiochemical properties (Clements *et al.*, 1993). Therefore, vanadium data were used in place of tantalum in addressing any modeling endpoint gaps (Lu, 2001).

7.3.1 Chromium, Tantalum, and Molybdenum Concentrations in Media

The data source for contaminant concentrations as shown in Table 7.9 is U.S. Army YPG (1999). For chromium, sediment samples were collected from different areas at YPG. Sampling locations are shown in Appendix D (Figures D-1 to D-8). Two of the sampling locations (B1 and B3) represent reference or background sites, as both sites are located upstream of YPG area. The other four sites represent the impact areas.

The range of chromium concentrations for background was between 5.6 mg/kg and 12 mg/kg. For the impact areas, the range of chromium concentrations was between 2.8 mg/kg and 13.0 mg/kg; the average concentration was 7.07 mg/kg. At YPG, air sampling was conducted for seven consecutive days at firing point 24 -500 Jammer on Kofa Range (U.S. Army YPG, 1999). The primary purpose of ambient air monitoring was to quantify air pollutant concentrations, which may have been emitted during the firing activities. Also, the YPG range workers located at or near this position during the daily operations were considered receptors of concern for the health risk assessment. Therefore, in this study, air data are used to assess the ERA. The range of chromium concentration in the air is between 3.00×10^{-6} mg/m^3 and 3.70×10^{-6} mg/m^3; the average concentration is 3.19×10^{-6} mg/m^3.

Table 7.9 Summary Contaminant Concentrations in Media at APG and YPG Sites

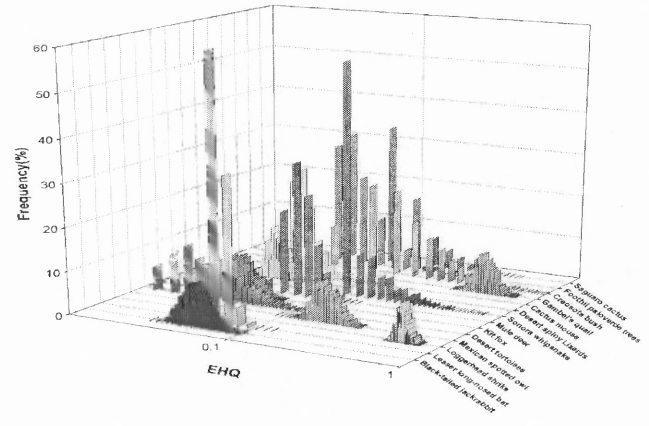
Contaminant	Soil–phase concentration EC_s (mg/kg)		Surface water concentration E_{sw} (mg/L)		Particulate air concentration EC_a (mg/m^3)		Soil to water distribution coefficient K_d (cm^3/g)
	APG	YPG	APG	YPG	APG	YPG	
Cr (VI)	7.07E+00	7.07E+00	4.71E-03	1.01E-01	3.19E-06	3.19E-06	At APG=1500, At YPG=70
Mo	1.30E+01	1.30E+01	1.45E-01	1.30E+00	5.89E-06	5.89E-06	At APG=90, At YPG=10
Ta	1.48E+01	1.48E+01	1.23E-02	6.71E-02	6.68E-06	6.68E-06	At APG=1200, At YPG=220

As mentioned earlier, equivalent concentrations have been used for the alternative metal coatings tantalum and molybdenum by assuming that the test firing continues at the same rate and the loss of a replacement metal is equivalent to that of the chromium. For APG, no soil/sediment data were available. However, as YPG has a greater gun barrel testing capability and longer testing history than APG and considering a worst-case scenario, the concentrations observed at YPG have been applied to APG.

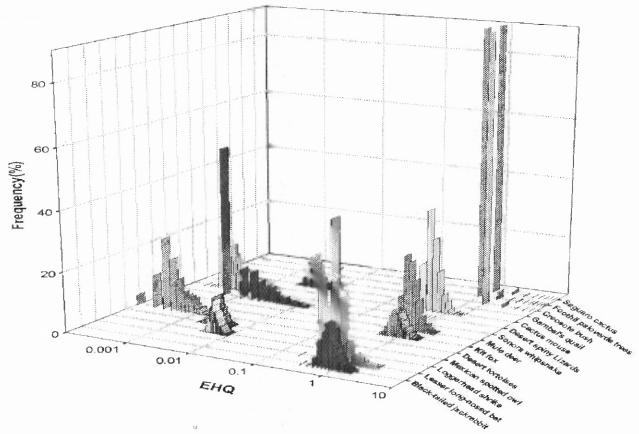
Based on the contaminant concentration in soil, the concentration in surface water at APG was estimated using distribution coefficients, which are a function of the type of soil as well as solution conditions. The distribution coefficient represents the partitioning behavior of the solute between the soil and bulk aqueous phase, assuming equilibrium. This coefficient can range over several orders of magnitude under varying conditions such as soil type, pH, redox potential, presence of other ions, and soil organic content (Yu *et al.*, 1993). Table 7.9 contains the chromium, molybdenum, and tantalum concentrations in media for both the APG and YPG sites.

7.3.2 Risks Results

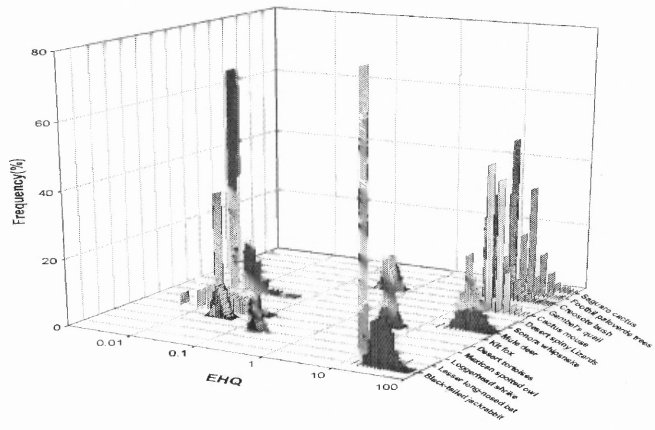
Comparing the risk distributions for the three metals (Figures 7.8 and 7.9); molybdenum poses the greatest risk for terrestrial animals at YPG site. The blacktailed-jackrabbits, lesser long-nosed bats, mule deer, and cactus mice are expected to experience (99% likelihood) reproductive impairment, which occurs through the reduction in size and weight of offspring. Additional effects from molybdenum exposure include reduced food intake and growth rate, liver and kidney damage, and depigmented hair. For terrestrial plants, there is 99% likelihood that growth retardation is likely for the creosote bush,



Chromium

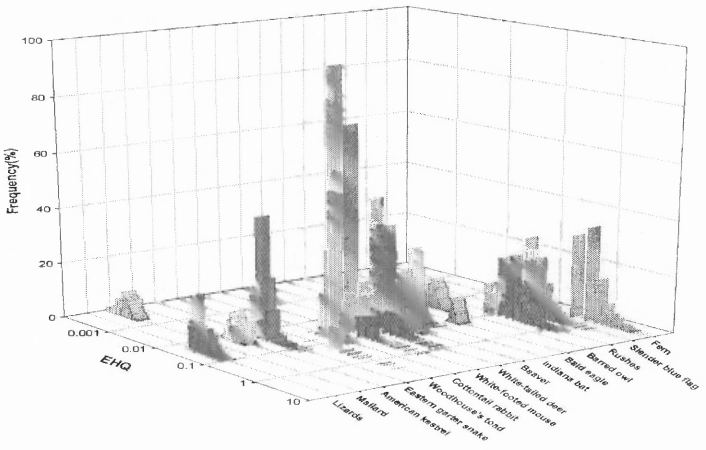


Tantalum

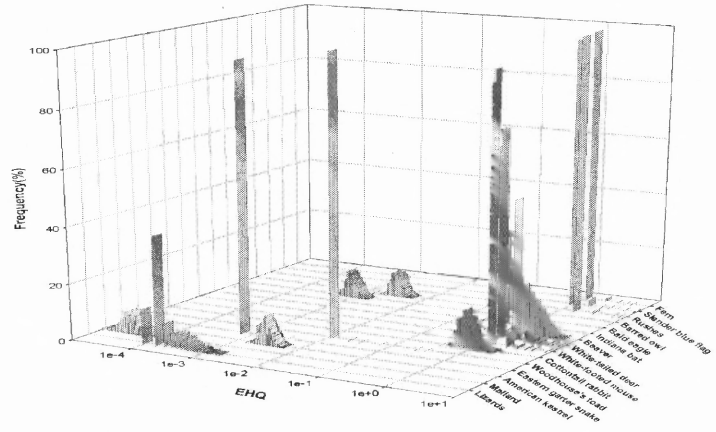


Molydenum

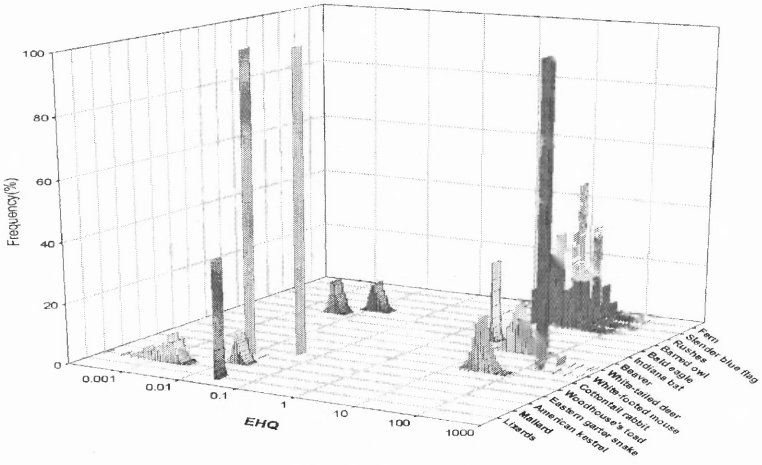
Figure 7.8 EHQ Distributions for Animal and Plant Receptors at YPG.



Chromium



Tantalum



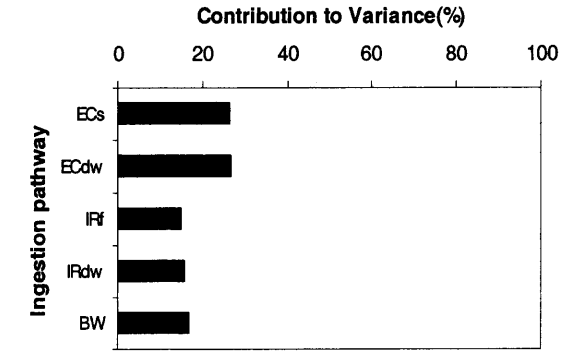
Molybdenum

Figure 7.9 EHQ Distributions for Terrestrial Animal and Plant Receptors at APG.

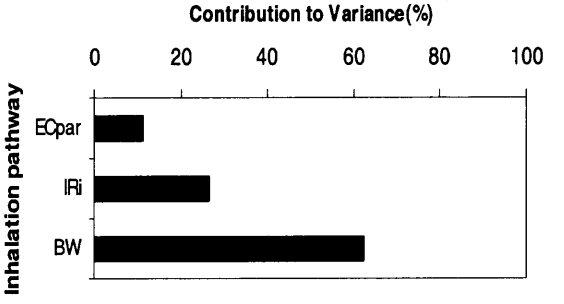
foothill paloverde trees, and saguaro cactus, as molybdenum would cause a reduction in their root weights. For chromium and tantalum, terrestrial animal exposure suggests no observable impact on a receptor's reproduction system is expected. Also for terrestrial plants, chromium and tantalum uptake is not expected to cause a decrease in root weight.

For APG, molybdenum again poses the greatest risk among the three metals where vulnerable receptors include white-footed mice, white-tailed deer, and cottontail rabbits. A 99% likelihood exists for these terrestrial animals that they would potentially experience a reduced food intake and growth rate, liver and kidney damage, depigmented hair, and reproductive impairment. For terrestrial plants, the probability distributions (Figure 7.9) suggest that growth retardation is likely due to a reduction in root weight. Based on a sensitivity analysis (Figure 7.10), contaminant concentration, food ingestion rate, water ingestion rate, and body weight are among the most influent parameters.

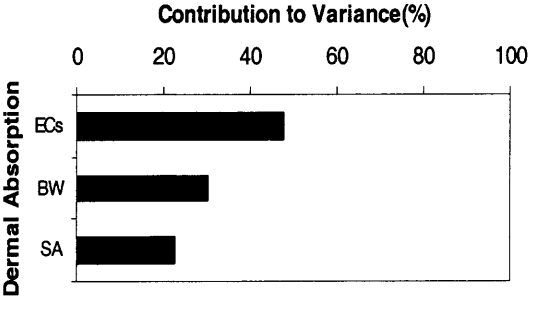
On the other hand, the probability distributions suggest that chromium and tantalum potentially pose little risk to terrestrial animals in that no observable impact on a receptor's reproduction or development is likely. However, the following receptors are potentially more vulnerable to chromium and tantalum exposure than other animals: white-footed mice, white tailed deer, and woodhouse toads. These three receptors may experience (0.3% likelihood) reproduction effects through the reduction in size and weight of offspring. Lastly, aquatic species exposure to molybdenum, chromium, and tantalum may potentially result in no observable impact on the receptor's survival, growth, and mortality.



Parameter	Definition
Ecs	Contaminant concentration in soil/sediment
Ecdw	Contaminant concentration in drinking water supply
Irf	Food ingestion rate
Irdw	Water ingestion rate
BW	Body weight



Parameter	Definition
ECpar	Concentration of particulate-bound contaminant in air
IRi	Inhalation rate
BW	Body weight



Parameter	Definition
ECs	Contaminant concentration in soil/sediment
BW	Body weight
SA	Surface area

Figure 7.10 Parameter Sensitivity Analysis, White Tailed Deer, APG.

In a field study, the U. S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) (U.S. YPG, 1999) collected ten rodents from the immediate down gradient of the gun position (approximately 12-13 km., downrange) on the Kofa Range area. Chromium was detected in the samples at 0.49-1.7 mg/kg. Six vegetation samples were analyzed from the sample site. Types of vegetation included creosote bushes, ocotillo, and paloverde. Chromium concentrations were detected in the range of 0.77-1.3 mg/kg. Compared to field data (Figure 7.11), body burdens for rodents and terrestrial plants were in agreement. Through the life history of the receptors, contaminant absorption, bioaccumulation, and excretion can be a very complicated process influenced by the variations of ecosystem conditions, contaminant characteristics, and receptor's physiological properties. The natural variations are difficult to reflect in any mathematical model where uncertainty and variability exist. To overcome these limitations, Monte Carlo simulations and probabilistic distributions are practical tools. Moreover, the ERA model results represent the risk as a probability distribution, which deals with uncertainly.

Another approach to validate the model results is to compare the model predictions with other models. In another risk assessment, the Conceptual Site Model (CSM) developed by USACHPPM was used for the environmental risk assessment at YPG (U.S. YPG, 1999). It was assumed that by sampling environmental resources and topographical features, the area where receptors more commonly contact potentially contaminated media would be determined. In the CSM model, only ingestion of soil and food was considered; therefore inhalation and dermal absorption were omitted. Receptors

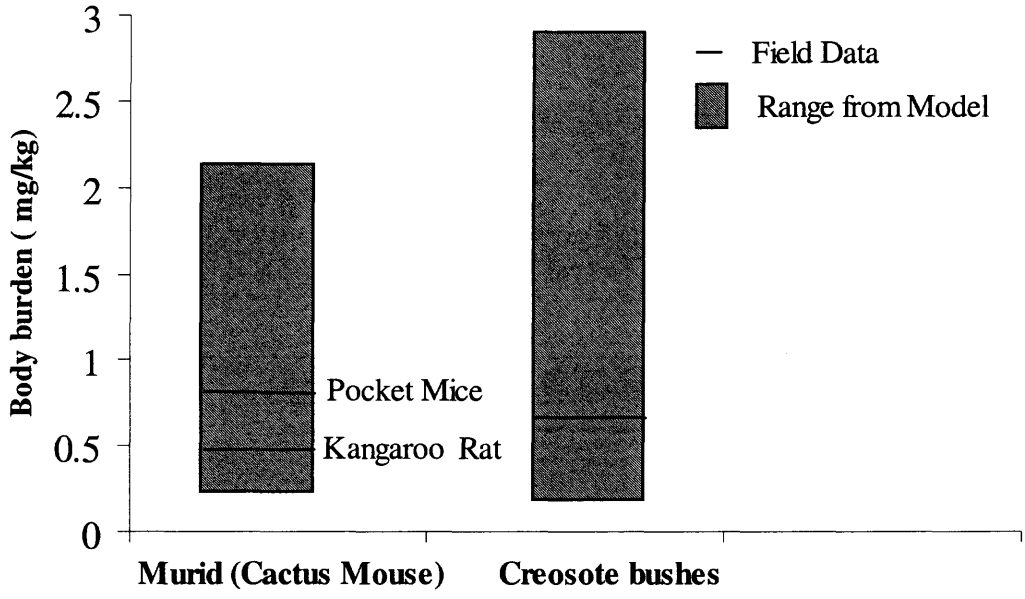


Figure 7.11 ERA Modeling Validation on Cr, YPG.

included black-tailed jackrabbit, kit fox, loggerhead shrike and great horned owl. The results, as shown in Figure 7.12, are based on the two sites at the YPG. The CSM uses a deterministic method to predict the risk, which is based on the input of a single value. In contrast, the ERA model propagates all the possible input values as a probabilistic distribution. Therefore, the ERA model yields a probability distribution for the risk assessment prediction. The predicted ranges are consistent with the CSM model prediction.

7.3.3 Summary

From the distributions, the overall risk posed by the metals followed the order of molybdenum > chromium > tantalum for both YPG and APG sites. Blacktailed-jackrabbits, lesser long-nosed bats, mule deer, and cactus mice at YPG are expected to exhibit reproductive impairment, which occurs through the reduction in size and weight of offspring. The creosote bush, foothill paloverde trees, and saguaro cactus are likely to demonstrate a reduction in root weight. For APG, vulnerable receptors include the white-footed mice, white-tailed deer, and cottontail rabbits; these terrestrial animals would potentially experience a reduced food intake and growth rate, liver and kidney damage, depigmented hair, and reproductive impairment. For terrestrial plants, the probability distributions suggest retardation in growth through a reduction in root weight. Aquatic species are potentially not expected to be impacted by exposure to molybdenum, chromium, and tantalum in the terms of survival, growth, and mortality.

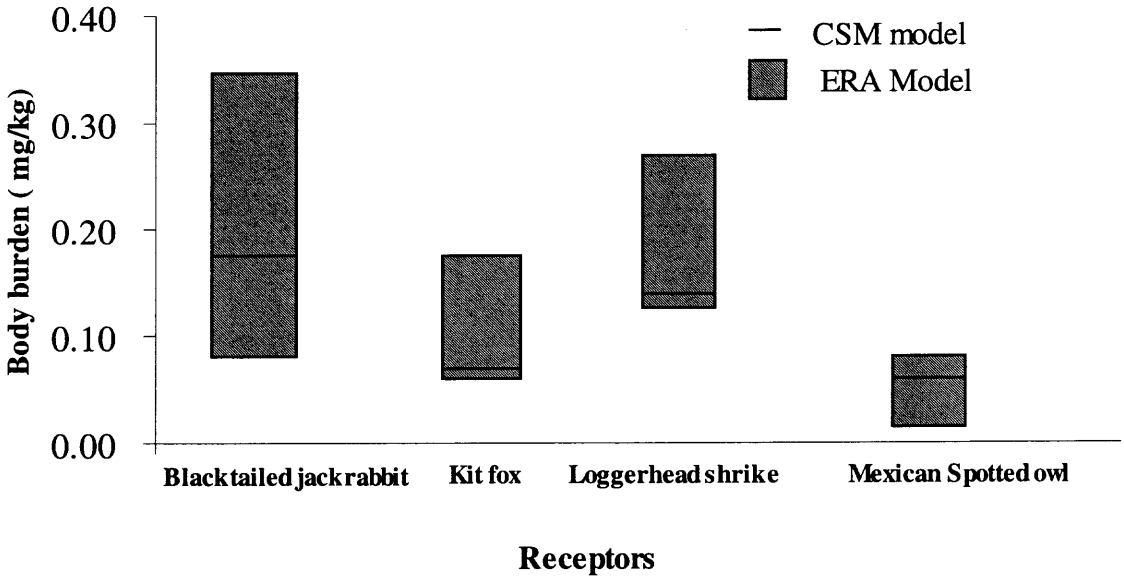


Figure 7.12 Chromium Body Burden in Receptors at YPG.

The results of Mo, which poses a significantly greater risk than Cr and Ta, may be attributed to the larger soil-to-plant transfer factor for Mo as compared to the other two metals. The greater transfer factor results in an increase in contaminant uptake in the plant. Therefore, increasing risk for animals with high vegetation diet. Consequently, the herbivores at both sites should be monitored and assessed for potential exposure.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

8.1 Conclusions

The overall uncertainty in the assumptions made for the risk assessment process can be broken down into two components: variability and uncertainty. Variability refers to spatial, temporal and individual differences in exposure and effect parameters (e.g., site-to-site or individual differences). Variability cannot be reduced by additional study or understanding but it can be better characterized. Uncertainty is the lack of knowledge of the true value of a parameter (e.g., in estimating biodegradation rates or the best guess on the amount of an ingredient accidentally spilled or ingested). Some elements of uncertainty can be reduced through further study (e.g. improved experimental design of a test). Because of the lack of understanding of the underlying processes and therefore very limited means for quantitative characterization, there are sources of uncertainty that cannot be reduced.

Uncertainties in exposure models can include how well the exposure model or its mathematical expression approximates the true relationships in the field as well as how realistic the exposure model assumptions are for the situation at hand. Uncertainty analysis of models is propagated with the error from each parameter in parameter inputs. The probabilistic distributions are used to demonstrate uncertainty of model outputs (result) or estimated exposure. Probabilistic distribution analysis emphasizes developing model input assumptions based on variable information and knowledge. Also,

probabilistic distributions are subjective evaluations of parameters where the nominal value is considered as the most likely value. A Monte-Carlo simulation is simply one of several mathematical techniques for performing probabilistic risk assessments. The Monte Carlo technique, as applied to exposure assessment, involves combining the results of hundreds or thousands of random samplings of values from input probability distributions in such a manner as to produce an output distribution, which reflects the expected range and frequency of exposures.

The ERA codes were modified to develop a computationally efficient method for uncertainty propagation by using the probabilistic distribution – Monte Carlo simulation approach. A probability distribution has been employed to characterize uncertainty and/or variability in some or all model inputs.

The probabilistic method uses full information methods by including all the information available about the variability and the uncertainty inherent in the assessment. The determination of which form of distribution function should be assigned to each parameter depends on site-specific data. Therefore, the distributions employed in this study are assembled from site - specific data and data existing in the most current literature. These were considered to be the most up to date parameter descriptions. Furthermore, the selected distribution criteria are based on the selection guideline of NPRC (1996), U.S. EPA (1998a), Warren-Hicks *et al.* (2002) and Schuhmacher *et al.* (2001). The iteration size corresponds to the number of repetitions used in the Monte Carlo simulation. In an ERA model, the selected iteration size is based on the 95^{th} confidence level. Based on Brush (1988), Cullen and Frey (1999), Havens *et al.* (2002) and the convergence study, the iteration size of 500 is deemed sufficient to characterize

the uncertainty for models. However, the results of ERA modeling also need to represent the statistical data such as the value of variance, skewness, etc. along with the histograms. Therefore, in applying the Monte Carlo simulation, the iteration size of 1000 is selected. The Monte Carlo Sampling method is applicable to a wide range of ecological risk assessment models associated with uncertainty propagation. The use of Visual Basic offers an alternative technique to develop a user-friendly probabilistic simulation tool. Microsoft Excel is also useful and easily used to calculate the descriptive statistics and probabilistic distributions.

VBA scripts were developed to set up and manage the Monte Carlo analysis. The appropriate distribution to describe each receptor's behavior was assigned in the VB codes. When a set of runs is initiated via the VBA codes, the Monte Carlo routine generates iterations from the distributions to set the input values for the current simulation. The existing input files are then saved in the same directory as the local database. The results are imported into Microsoft Excel.

ERA model was verified and validated. For model verification, the ERA code is written in Visual Basic and integrated into the software by linking it with a Windows-based interface and the DBMS. The developed ERA software was subsequently verified. From the results for white-tailed deer and American kestrel, the ERA model predicted ADD values in agreement with the spreadsheet calculated ADD values. Moreover, the results demonstrated that as a contaminant concentration in a medium increases, the body burden or applied daily dose increases. Therefore, as the media concentration increases, the risk on the ecosystem rises as would be expected given the associated algorithms.

Case study was performed using ERA software. Monte Carlo simulation was performed using a distribution of measured soil, water and air concentrations to produce a credible range of exposure estimates. Monte-Carlo analysis was used to evaluate the uncertainty associated with each sensitive input parameter. One of the most important steps in this process was the development of distributions for each parameter that could be sampled during the Monte-Carlo analysis. The application of distribution selection criteria established ensured consistency in the procedures for evaluating model prediction error across sites and also ensured that the sampling distributions represented the actual site-specific uncertainty and variation in the parameters. Therefore, the Monte Carlo uncertainty analysis results reflect the true model prediction error associated with a specific site and parameter set. Results from the case study were presented in terms of descriptive statistics, which include the mean, median, etc., and histograms, which plot the frequency of sample data grouped into intervals or bins. The overall risk characterization can be described in terms of a range of risk values from the Monte Carlo simulation distributions.

Risks from exposure to DU at two U.S Army sites, APG and YPG, were characterized based on the data available. Exposure pathways for terrestrial and aquatic plants and animals were applied in software developed using Visual Basic 6.0 with associated parameters stored in the Microsoft Access DBMS. To characterize risk and address uncertainty, the model employs Monte Carlo simulations for assessing parameter and risks as probabilistic distributions. Results from the ERA model suggest that at YPG, a reduction in plant root weight is considered likely to occur from exposure to uranium. For most terrestrial animals at YPG, the predicted DU dose is less than that resulting in a

decrease in offspring. However, for the lesser long-nosed bat, reproductive effects are expected to occur in the reduction in size and weight of offspring. Furthermore, the ingestion pathway is the most critical where four parameters strongly influence the risk distribution: contaminant concentration, food ingestion rate, water ingestion rate, and body weight. For dermal exposure, contaminant concentration in soil and the surface area exposed also affect the risk distribution. At APG, uranium uptake may not likely affect survival of aquatic plants and animals. However, data were limited reflecting the risk observed and further field investigations at both sites are recommended. Through model validation, the results from the ERA model are consistent with sampling data from field studies of Ebinger *et al.* (1996).

From the distributions, the overall risk posed by the metals followed the order of molybdenum > chromium > tantalum for both YPG and APG sites. Blacktailed-jackrabbits, lesser long-nosed bats, mule deer, and cactus mice at YPG are expected to exhibit reproductive impairment, which occurs through the reduction in size and weight of offspring. The creosote bush, foothill paloverde trees, and saguaro cactus are likely to demonstrate a reduction in root weight. For APG, vulnerable receptors include the white-footed mice, white-tailed deer, and cottontail rabbits; these terrestrial animals would potentially experience a reduced food intake and growth rate, liver and kidney damage, depigmented hair, and reproductive impairment. For terrestrial plants, the probability distributions suggest retardation in growth through a reduction in root weight. Aquatic species are potentially not expected to be impacted by exposure to molybdenum, chromium, and tantalum in the terms of survival, growth, and mortality. The results of Mo posing a significantly greater risk than Cr and Ta may be attributed to the larger soil-

to-plant transfer factor for Mo as compared to the other two metals. The greater transfer factor results in an increase in contaminant uptake in the plant. Therefore, increasing risk for animals with high vegetation diet. Consequently, the herbivores at both sites should be monitored and assessed for potential exposure.

The results from the ERA model are consistent with sampling data from field studies of the U. S. Army Center for Health Promotion and Preventive Medicine, 1999. Through the life history of the receptors, contaminant absorption, bioaccumulation, and excretion can be a very complicated process influenced by the variations of ecosystem conditions, contaminant characteristics, and receptor's physiological properties. The natural variations are difficult to reflect in any mathematical model where uncertainty and variability exist. To overcome these limitations, Monte Carlo simulations and probabilistic distributions are practical tools. Moreover, the ERA model results represent the risk as a probability distribution, which deals with uncertainly.

Another approach to validate the model results is to compare the model predictions with other models. The Conceptual Site Model (CSM) was used for the environmental risk assessment at YPG. Only ingestion of soil and food was considered. The CSM uses a deterministic method to predict the risk, which is based on the input of a single value. In contrast, the ERA model propagates all the possible input values as a probabilistic distribution. Therefore, the ERA model yields a probability distribution for the risk assessment prediction. The predicted ranges are consistent with the CSM model prediction.

8.2 Recommendations for Future Work

Based on this work, the following are recommended for improving an uncertainty analysis and the ERA software.

1. To accurately address contaminant mobility and bioavailability, the ERA will be linked with speciation and transport models to account for spatial and temporal aspects, which will assist in better quantifying receptor exposure and support advancing the ability to apply mobile and available concentrations found in subsurface environments.
2. Combining the ecological risk assessment with a life cycle approach, which will take into account the overall cradle to grave perspective for sustainable development.
3. Better toxicological data are needed to qualify the magnitude of potential impacts to receptors from exposure to single as well as multiple contaminants.
4. From the case study, APG and YPG were identified as baseline ecosystems for the ERA model, which represent coastal and desert ecosystems, respectively. To apply the ERA model to other sites, the following guidance should be considered.

8.3 Expanding the ERA

Applying the ERA model to other sites, the types of site data need for ecological risk assessment should include the following: contaminant identities; contaminant concentrations in the sources and media of interest; characteristics of sources, especially

information related to release potential; and characteristics of the environmental setting that may affect the fate, transport, and persistence of the contaminants. To ensure that all risk assessment data needs will be met, the following data must be classified: the type and duration of possible exposures, potential exposure routes (e.g., ingestion, inhalation, dermal contact pathways), and exposure points for each medium. The relative importance of the potential exposure routes and exposure points in determining risks should be discussed. Available site information must be reviewed to identify all potential or suspected sources of contamination, types and concentrations of contaminants detected at the site, potentially contaminated media, and potential exposure pathways, including receptors. Identification of potential exposure pathways, especially the exposure points, is a key element in the determination of data needs for the risk assessment. Background sampling must be conducted to distinguish site-related contamination from naturally occurring or other non-site-related levels of chemicals.

Background samples are collected at or near the site in areas not influenced by site contamination. They are collected from each medium of concern in these offsite areas. That is, the locations of background samples must be area that could not have received contamination from the site, but do have the same basic characteristics as the medium of concern at the site. For risk assessment purposes, media of concern at the site are:

- Any currently contaminated media to which individuals may be exposed or through which chemicals may be transported to potential receptors; and
- Any currently uncontaminated media that may become contaminated in the future due to contaminant transport.

Several medium specific factors in sampling may influence the risk assessment; the assessor should make sure that appropriate samples are collected from each medium of concern. Areas of concern refer to the general sampling locations at or near the site and should be identified based on site-specific characteristics.

In some instances, it may be necessary to estimate concentrations that are representative of the site as a whole, in addition to each area of concern. In these cases, two conditions generally should be met in defining areas of concern; (a) the boundaries of the areas of concern should not overlap and (b) all of the areas of concern together should account for the entire area of the site.

Depending on the exposure pathways that are being evaluated in the risk assessment, the types of chemicals expected at a site may dictate the site areas and media sampled. Due to differences in the relative toxicities of different species of the same chemical, the species should be noted when possible. In addition to medium-specific concerns, there may be several potential current and future routes of contaminant transport within a medium and between media at a site. Therefore, when possible, samples should be collected based on routes of potential transport.

Soil represents a medium of direct contact exposure and often is the main source of contaminants released into other media. As such, the number, location, and type of samples collected from soils will have a significant effect on the risk assessment. One of the largest problems in sampling soil is that its generally heterogeneous nature makes collection of representative samples difficult. Therefore, a large number of soil samples may be required to obtain sufficient data to calculate an exposure concentration. Composite samples sometimes are collected to obtain a more homogeneous sample of a

particular area; however, composite samples also serve to mask contaminant hot spots as well as areas of low contaminant concentration. Areas of very high contaminant concentrations may have a significant impact on direct contact exposures. The sampling plan should consider characterization of this spots through extensive sampling, field screening, visual observations, or a combination of the above.

Sample depth should be applicable for the exposure pathways and contaminant transport routes of concern and should be chosen purposively within that depth interval. If a depth interval is chosen purposively, a random procedure to select a sampling point may be established. Assessment of surface exposures will be more certain if samples are collected from the shallowest depth that can be practically obtained. Subsurface soil samples are important, however, if soil disturbance is likely or if leaching of chemicals to ground water is of concern, or if the site has current or potential agricultural uses.

For ground water, considerable expense and effort normally are required for the installation and development of monitoring wells and the collection of ground water samples. Wells must not introduce foreign materials and must provide a representative hydraulic connection to the geologic formations of interest. In addition, ground-water samples need to be collected using and approach that adequately defines the contaminant plume with respect to potential exposure points. Existing potential exposure points (e.g., existing drinking water wells) should be sampled.

For surface water and sediment, samples need to be collected from any nearby surface water body potentially receiving discharge from the site. Samples are needed at a sufficient number of sampling points to characterize exposure pathways and at potential

discharge points to the water body to determine if the site is contributing to surface water/sediment contamination.

Some important considerations for surface water/sediment sampling that may affect the risk assessment for various types and portions of water bodies. Fast moving waters such as rivers and streams, the variations in mixing across the stream channel and downstream in rivers and streams can make it difficult to obtain representative samples. Although the selection of sampling points will be highly dependent on the exposure pathways of concern for a particular site, samples generally should be taken both toward the middle of the channel where the majority of the flow occurs and along the banks where flow is generally lower. Sampling locations should be downgradient of any possible contaminant sources such as effluent outfalls. Any facilities upstream that affect flow volume or water quality should be considered during the timing of sampling. Background releases upstream could confound the interpretation of sampling results by diluting contaminants or by increasing contaminant loads. In general, sampling should begin downstream and proceed upstream.

In the case of slow moving waters, such as lakes, ponds, and impoundments, slow moving waters require more samples than fast moving waters because of the relatively low degree of mixing of slow moving waters. Thermal stratification is a major factor to be considered when sampling lakes. If a water body is stratified, samples from each layer should be obtained. Vertical composites of these layers then may be made, if appropriate. For small shallow ponds, only one or two sample locations (e.g., the intake and the deepest points) may be adequate depending on the exposure pathways of concern for the

site. Periodic release of water should be considered when sampling impoundments, as this may affect chemical concentrations and stratification.

For estuaries, contaminant concentrations in estuaries will depend on tidal flow and salinity stratification, among other factors. To obtain a representative sample, sampling should be conducted through a tidal cycle by taking three sets of samples on a given day at low tide, high tide and half tide. Each layer of salinity should be sampled.

Sediment samples should be collected in a manner that minimizes disturbance of the sediments and potential contamination of subsequent samples. Sampling in flowing waters should begin downstream and end upstream. As mentioned, it is important to obtain data that will support the evaluation of the potential exposure pathways of concern. For example, for pathways such as incidental ingestion, sampling of near-shore sediments may be important

For air samples, the goal of air sampling at a site is to adequately characterize air-related contaminant exposures. When evaluating long-term inhalation exposures, sample results should be representative to the long-term average air concentrations at the long-term exposure points. If acute or subchronic exposures resulting from episodes of unusually large emissions are of interest, sampling over a much smaller time scale would be needed.

Selection of appropriate type of air monitor will depend on the emission source(s) being investigated as well as the exposure routes to be evaluated. For example, if inhalation of dust is an exposure pathway of concern, then the monitoring equipment must be able to collect respirable dust samples. Site-specific meteorological conditions should be obtained (e.g., from the National Weather Service) or recorded during the air-

sampling program with sufficient detail and quality assurance to substantiate and explain the air sampling results. The review of these meteorological data can indicate the sampling locations and frequencies.

For biota samples, organisms sampled for ecological risk assessment purposes should be those that are likely to be consumed by receptors of concern. This may include animals such as fish, fowl, and terrestrial mammals (e.g., rabbit, deer), as well as plants, vegetables and fruits. An effort should be made to sample species that are consumed most frequency by those receptors.

Whole body measurements may be needed, however, for certain species of fish and /or for environmental risk assessments. For example, for some species, especially small ones (e.g., smelt), whole body concentrations are most appropriate. Any conditions that may result in non-representative sampling, such as sampling during a species' migration or when plants are not in season should be avoided.

In the ERA software, the model parameters and data are already stored in a modifiable database management system for two baseline systems, coastal and desert ecosystems. To modify software for other ecosystems, site data needed are discussed above. Therefore, the user can benefit by using this software for conducting a site-specific ecological risk assessment.

APPENDIX A

ERA MODEL EQUATIONS

The following description represents a compilation of exposure formulas that were primarily derived from EPA's wildlife exposure factors handbook (EPA 1993a).

Terrestrial Plants

Root Uptake from Root-zone Soil to Roots

$$C_{pr} = EC_{rzs} \times K_{ps1} \qquad \text{(Hope, 1995)}$$

Where:

C_{pr} = contaminant concentration in plant roots, mg/kg

EC_{rzs} = contaminant concentration in root-zone soil, mg/kg

K_{ps1} = plant-soil partition coefficient for root-zone soil to roots, mg/kg(soil)/mg/kg(roots)

Submodel:

$$K_{ps1} = 270 \times K_{ow}^{-0.58} \qquad \text{(McKone, 1993)}$$

Where:

K_{ow} = contaminant-specific octanol-water partition coefficient, mol/L(water)/mol/L(octanol)

Calibration:

K_{ow} lookup from MEPAS chemical database or estimate from the equations in Appendix H

Root Uptake from Root-zone Soil Solution to Roots

$$C_{pr} = EC_{sw} \times RCF \qquad \text{(Hope, 1995)}$$

Where:

EC_{sw} = contaminant concentration in surface water in contact with roots, mg/L

RCF = root concentration factor, L/kg

Submodel:

$$RCF = 0.82 + 0.03 \times K_{ow}^{0.77} \quad \text{(Briggs } et\ al.\text{, 1983)}$$

Root Uptake from Root-zone Soil to Above-ground Plant Parts

$C_{pa} = EC_{rzs} \times (K_{ps2}, B_r, B_v)$ (Note that one or the other of the terms in brackets would be used depending on whether the contaminant was organic (K_{ps2}) or inorganic (B_r, B_v). Equation modified from Hope, 1995)

Where:

C_{pa} = Contaminant concentration in above-ground plant parts, mg/kg

K_{ps2} = plant-soil partition coefficient for root-zone soil to above-ground plant parts, mg/kg(soil)/mg/kg(above-ground plant)

Br = Bioconcentration factor for vegetative plant parts,

mg/kg(soil)/mg/kg(vegetative plant)

B_v = Bioconcentration factor for nonvegetative plant parts,

mg/kg(soil)/mg/kg(nonvegetative plant)

Submodel:

$$K_{ps2} = 7.7 \times K_{ow}^{-0.58} \quad \text{(McKone, 1993)}$$

Calibration:

Br, Bv lookup from U.S. Department of Energy (1996) and Base *et al.* (1984)

Foliar Uptake (vapor)

$$C_{pa} = EC_{vap} \times K_{pa} \qquad \text{(Hope, 1995)}$$

Where:

K_{pa} = plant-air partition coefficient for air to above-ground plant parts, m^3/kg

Submodel:

$$K_{pa} = [0.5 + (0.4 + 0.01K_{ow}) \times \frac{RT}{H}] \times 10^{-3}\ m^3/kg \qquad \text{(Reiderer, 1990)}$$

R = universal gas constant, 8.314 Pa-m^3/mol/K

T = temperature, K

H = contaminant-specific Henry's law constant, Pa-m^3/mol

Foliar Uptake (particulates)

$$C_{pa} = EC_{par} \times K_{pa} \qquad \text{(Hope, 1995)}$$

Terrestrial Animals

Direct Absorption from Dermal Exposure

$$ADD_{dcs} = [(SA \times AF \times P_{cs} \times EC_s \times CF \times \alpha_d)/BW) \times \theta \times \psi$$

(modified from U.S EPA, 1991)

$$C_{dc} = ADD_{dc}/k_e \qquad \text{(Hope, 1995)}$$

Where

ADD_{dc} = absorbed daily dose from dermal contact, mg/kg

C_{dc} = contaminant body burden in receptor from dermal contact, mg/kg

EC_s = contaminant concentration in soil, mg/kg

SA = surface area of ecological receptor, cm^2

AF = soil-to-skin adherence factor, mg/ cm^2

P_c = fraction of receptor surface area in contact with soil per day, d^{-1}

α_d = contaminant-specific dermal absorption factor, mg/kg (contaminant body burden) / mg/kg (absorbed daily dose)

k_e = contaminant-specific depuration rate, d^{-1}

BW = body weight of receptor, kg

CF = conversion factor, 1×10^{-6} kg/mg

θ= site use factor, (ratio of contaminant area to home range)

ψ = seasonality factor; (fraction of time per year receptor occurs at site)

Submodel:

Birds: $SA = 10 \times (BW \times 1000)^{0.667}$ (U.S. EPA, 1993a)

Mammals: $SA = 12.3 \times (BW \times 1000)^{0.65}$ (U.S. EPA, 1993a)

Woodhouse's toads: $SA = 0.953 \times (BW \times 1000)^{0.725}$ (U.S. EPA, 1993a)

Lizards: $SA = 8.42 \times (BW \times 1000)^{0.694}$ (U.S EPA 1993a-salamander applied to lizards)

Western aquatic garter snake: $= 2 \times \pi \times 1$ cm radius (1 cm + 106 cm length) (U.S EPA, 1993a and Stebbins 1985)

Terrestrial arthropods: 0.0002 cm^2 (PNNL, 1998)

Calibration:

α_d = See MEPAS chemical database and U. S. EPA(1995, 1989a)

k_e = See CRCIA (PNNL,1998)

P_{cs} = mammal: 0.22, other vertebrates: 0.25, arthropods: 1(Maughan, 1993)

BW = lookup for species using EPA (1993a), Dunning (1993), Silva and Downing (1995), Nagy (1983)

$\theta = 1$

ψ = 1 for all species except common snipe (0.33), bufflehead (0.5), Forster's tern (0.5), cliff swallow (0.5), and bald eagle (0.5).

Inhalation of Volatilized Contaminants

$ADD_{iv} = [(IR_i \times EC_{va})/BW] \times \theta \times \psi \times B_t$ (modified from Hope (1995))

$C_{iv} = ADD_{iv} \times (\alpha_v / k_e)$ (Hope ,1995)

where:

ADD_{iv} = applied daily dose from inhalation of volatilized contaminants, mg/kg

C_{iv} = contaminant body burden in receptor from vapor inhalation, mg/kg

IR_i = inhalation rate, m^3/day

B_t = fraction of day spent in burrow, hr/24hr

EC_{vap} = concentration of volatilized contaminant in air, mg/ m^3

α_v = inhalation absorption factor, mg/kg (contaminant body burden) / mg/kg (applied daily dose)

Submodel:

IR_i EPA (1993a) and CRCIA (PNNL,1998):

Species	IR_i
Mammals	$2 \times 0.5458 \times BW^{0.80}$
Birds	$2 \times 0.4089 \times BW^{0.77}$
Woodhouse's toad	5.8×10^{-4}
Lizards and western aquatic garter snake	$0.00045 \times (BW \times 1000)^{0.8}$
Terrestrial arthropods	$0.00045 \times (BW \times 1000)^{0.8}$

Calibration:

α_v lookup from CRCIA (PNNL,1998) and Owen (1990)

IR_i lookup for species using EPA (1993a) or estimate from submodel

Inhalation of Fugitive Dust

$$ADD_{ip} = [IR_i \times EC_{par})/BW] \times \theta \times \psi \quad \text{(Hope, 1995)}$$

$$C_{ip} = ADD_{ip} \times (\alpha_p / k_e) \quad \text{(Hope,1995)}$$

Where:

ADD_{iv} = applied daily dose from inhalation of volatilized contaminants, mg/kg

EC_{par} = concentration of particulated-bound contaminant in air, mg/ m^3

C_{iv} = contaminant body burden in receptor from particulate inhalation, mg/kg

α_p = particulate inhalation absorption factor, mg/kg (contaminant body burden) / mg/kg (applied daily dose)

Calibration: α_p lookup from CRCIA (PNNL,1998) and Owen (1990)

Incidental Ingestion of Soil or Sediment

$$ADD_{si} = (EC_s \times FS \times IR_f) / BW \times \theta \times \psi$$

(modified from U.S. EPA (1993a) using site use fractions as above)

Where:

ADD_{si} = applied daily dose from incidental ingestion of soil or sediment, mg/kg,

EC_s = contaminant concentration in surficial soil or sediment, mg/kg

FS = mass fraction of soil or sediment in the diet, as percentage of diet on dry weight basis

IR_f = food ingestion rate on dry-weight basis, kg/day

Submodel: IR_f (U.S. EPA, 1993a)

Species	IR_f
Mammals	$= 0.235\ BW^{0.822}$
Birds	$= 0.0582\ BW^{0.651}$
Woodhouse's toad	$= 0.013(\ BW \times 1000)^{0.773}$
Lizards and western aquatic garter snake	$= 0.013(\ BW \times 1000)^{0.773}$

Calibration:

FS lookup for species using U.S. EPA (1993a)

IR_f lookup for species using U.S. EPA (1993a) or estimate from submodel

Ingestion of Water

$ADD_{wi} = EC_{dw} \times (IR_{dw}/BW) \times \theta \times \psi$ (modified from EPA (1993a) using site use fractions as above)

Where:

ADD_{wi} = applied daily dose from drinking water, mg/L-day

EC_{dw} = average contaminant concentration at drinking water supply, mg/L

IR_{dw} = ingestion rate of drinking water, mg/day

Submodel:

IR_{dw} (U.S. EPA 1993a)

Species	IR_{dw}
Mammals	$= 0.099 \times BW^{0.90}$
Birds	$= 0.059 \times BW^{0.67}$
Woodhouse's toad	0
Lizards and western aquatic garter snake	0
Terr. arthropods	0

Calibration:

IR_{dw} lookup for species using EPA (1993a) or estimate from submodel

Ingestion of Food

$$ADD_{fi} = \sum_{k=1}^{m} (C_k \times FR_{fk} \times IR_f/BW) \times \theta \times \psi \quad \text{(modified from Hope 1995)}$$

ADD_{fi} = applied daily dose from ingestion of contaminated food, mg/kg

m = number of food items in the diet of the receptor species

C_k = contaminant concentration in the k^{th} food item, mg/kg

FR_{fk} = wet weight fraction of the k^{th} food item in receptor diet, kg (food)/kg(diet)

Submodel

$C_k = (ADD_{fi} + ADD_{wi} + ADD_{si}) \times (\alpha_{ing}/ k_e) + C_{other}$ (modified from Hope, 1995)

where:

C_k = contaminant concentration in food item k resulting from all appropriate uptake pathways (ingestion, inhalation, dermal absorption and etc.), mg/kg

C_{other} = contaminant concentration in food item k resulting from exposure pathways other than ingestion (inhalation, dermal absorption, direct absorption, plant root uptake and etc.) mg/kg

α_{ing} = ingestion absorption factor, mg/kg (contaminant body burden) / mg/kg (applied daily dose)

Calibration:

FR_{fk} lookup for species using U.S. EPA (1993a)

α_{ing} Lookup from Owen (1990) and MEPAS chemical database

Aquatic Species

Direct Contact

$$C_{aq} = EC_{sw} \times BCF$$

Where:

C_{aq} = contaminant body burden in aquatic receptor, mg/kg

BCF = contaminant-specific bioconcentration factor, L/kg

Calibration:

BCF = lookup from MEPAS chemical database

Values for inorganic contaminants (metal) may also be obtained from the literature (Maughan, 1993) and database (ECOTOX, 2003) or estimated from empirical equation derived by Sample *et al.* (1996) using the water solubility (K_{so} mg/L) of a contaminant:

$$\text{Log BCF} = 2.791 - 0.564 \log K_{so}$$

APPENDIX B

SHAPIRO -WILK TEST

Table B.1 Coefficient (a_{N-I+1}) for Shapiro-Wilk W-Test of Normality (McBean and Rovers, 1998)

i/n	2	3	4	5	6	7	8	9	10	
1	0.7071	0.7071	0.6872	0.6646	0.6431	0.6233	0.6052	0.5888	0.5739	
2	—	0.0000	0.1677	0.2413	0.2806	0.3031	0.3164	0.3244	0.3291	
3	—	—	—	0.0000	0.0875	0.1401	0.1743	0.1976	0.2141	
4	—	—	—	—	—	0.0000	0.0561	0.0947	0.1224	
5	—	—	—	—	—	—	—	0.0000	0.0399	
i/n	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1	0.5601	0.5475	0.5359	0.5251	0.5150	0.5056	0.4968	0.4886	0.4808	0.4734
2	0.3315	0.3325	0.3325	0.3318	0.3306	0.3290	0.3273	0.3253	0.3232	0.3211
3	0.2260	0.2347	0.2412	0.2460	0.2495	0.2521	0.2540	0.2553	0.2561	0.2565
4	0.1429	0.1586	0.1707	0.1802	0.1878	0.1939	0.1988	0.2027	0.2059	0.2085
5	0.0695	0.0922	0.1099	0.1240	0.1353	0.1447	0.1524	0.1587	0.1641	0.1686
6	0.0000	0.0303	0.0539	0.0727	0.0880	0.1005	0.1109	0.1197	0.1271	0.1334
7	—	—	0.0000	0.0240	0.0433	0.0593	0.0725	0.0837	0.0932	0.1013
8	—	—	—	—	0.0000	0.0196	0.0359	0.0496	0.0612	0.0711
9	—	—	—	—	—	—	0.0000	0.0163	0.0303	0.0422
10	—	—	—	—	—	—	—	—	0.0000	0.0140
i/n	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1	0.4643	0.4590	0.4542	0.4493	0.4450	0.4407	0.4366	0.4328	0.4291	0.4254
2	0.3185	0.3156	0.3126	0.3098	0.3069	0.3043	0.3018	0.2992	0.2968	0.2944
3	0.2578	0.2571	0.2563	0.2554	0.2543	0.2533	0.2522	0.2510	0.2499	0.2487
4	0.2119	0.2131	0.2139	0.2145	0.2148	0.2151	0.2152	0.2151	0.2150	0.2148
5	0.1736	0.1764	0.1787	0.1807	0.1822	0.1836	0.1848	0.1857	0.1864	0.1870
6	0.1399	0.1443	0.1480	0.1512	0.1539	0.1563	0.1584	0.1601	0.1616	0.1630
7	0.1092	0.1150	0.1201	0.1245	0.1283	0.1316	0.1346	0.1372	0.1395	0.1415
8	0.0804	0.0878	0.0941	0.0997	0.1046	0.1089	0.1128	0.1162	0.1192	0.1219
9	0.0530	0.0618	0.0696	0.0764	0.0823	0.0876	0.0923	0.0965	0.1002	0.1036
10	0.0263	0.0368	0.0459	0.0539	0.0610	0.0672	0.0728	0.0778	0.0822	0.0862
11	0.0000	0.0122	0.0228	0.0321	0.0403	0.0476	0.0540	0.0598	0.0650	0.0697
12	—	—	0.0000	0.0107	0.0200	0.0284	0.0358	0.0424	0.0483	0.0537
13	—	—	—	—	0.0000	0.0094	0.0178	0.0253	0.0320	0.0381
14	—	—	—	—	—	—	0.0000	0.0084	0.0159	0.0227
15	—	—	—	—	—	—	—	—	0.0000	0.0076
i/n	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
1	0.4220	0.4188	0.4156	0.4127	0.4096	0.4068	0.4040	0.4015	0.3989	0.3964
2	0.2921	0.2898	0.2876	0.2854	0.2834	0.2813	0.2794	0.2774	0.2755	0.2737
3	0.2475	0.2463	0.2451	0.2439	0.2427	0.2415	0.2403	0.2391	0.2380	0.2368
4	0.2145	0.2141	0.2137	0.2132	0.2127	0.2121	0.2116	0.2110	0.2104	0.2098
5	0.1874	0.1878	0.1880	0.1882	0.1883	0.1883	0.1883	0.1881	0.1880	0.1878
6	0.1641	0.1651	0.1660	0.1667	0.1673	0.1678	0.1683	0.1686	0.1689	0.1691
7	0.1433	0.1449	0.1463	0.1475	0.1487	0.1496	0.1503	0.1513	0.1520	0.1526
8	0.1243	0.1265	0.1284	0.1301	0.1317	0.1331	0.1344	0.1356	0.1366	0.1376
9	0.1066	0.1093	0.1118	0.1140	0.1160	0.1179	0.1196	0.1211	0.1225	0.1237
10	0.0899	0.0931	0.0961	0.0988	0.1013	0.1036	0.1056	0.1075	0.1092	0.1108

Table B.2 Coefficient (a_{N-I+1}) for Shapiro-Wilk W-Test of Normality (continued) (McBean and Rovers, 1998)

i/n	31	32	33	34	35	36	37	38	39	40
11	0.0739	0.0777	0.0812	0.0844	0.0873	0.0900	0.0924	0.0947	0.0967	0.0896
12	0.0585	0.0629	0.0669	0.0706	0.0739	0.0770	0.0798	0.0824	0.0848	0.0870
13	0.0435	0.0485	0.0530	0.0572	0.0610	0.0645	0.0677	0.0706	0.0733	0.0759
14	0.0289	0.0344	0.0395	0.0441	0.0484	0.0523	0.0559	0.0592	0.0622	0.0651
15	0.0144	0.0206	0.0262	0.0314	0.0361	0.0404	0.0444	0.0481	0.0515	0.0546
16	0.0000	0.0068	0.0131	0.0187	0.0239	0.0287	0.0331	0.0372	0.0409	0.0444
17	—	—	0.0000	0.0062	0.0119	0.0172	0.0220	0.0264	0.0305	0.0343
18	—	—	—	—	0.0000	0.0057	0.0110	0.0158	0.0203	0.0244
19	—	—	—	—	—	—	0.0000	0.0053	0.0101	0.0146
20	—	—	—	—	—	—	—	—	0.0000	0.0049
i/n	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
1	0.3940	0.3917	0.3894	0.3872	0.3850	0.3830	0.3808	0.3789	0.3000	0.3751
2	0.2719	0.2701	0.2684	0.2667	0.2651	0.2635	0.2620	0.2604	0.2589	0.2574
3	0.2357	0.2345	0.2334	0.2323	0.2313	0.2302	0.2291	0.2281	0.2271	0.2260
4	0.2091	0.2085	0.2078	0.2072	0.2065	0.2058	0.2052	0.2045	0.2038	0.2032
5	0.1876	0.1874	0.1871	0.1868	0.1865	0.1862	0.1859	0.1855	0.1851	0.1847
6	0.1693	0.1694	0.1695	0.1695	0.1695	0.1695	0.1695	0.1693	0.1692	0.1691
7	0.1531	0.1535	0.1539	0.1542	0.1545	0.1548	0.1550	0.1551	0.1553	0.1554
8	0.1384	0.1392	0.1398	0.1405	0.1410	0.1415	0.1420	0.1423	0.1427	0.1430
9	0.1249	0.1259	0.1269	0.1278	0.1286	0.1293	0.1300	0.1306	0.1312	0.1317
10	0.1123	0.1136	0.1149	0.1160	0.1170	0.1180	0.1189	0.1197	0.1205	0.1212
11	0.1004	0.1020	0.1035	0.1049	0.1062	0.1073	0.1085	0.1095	0.1105	0.1113
12	0.0891	0.0909	0.0927	0.0943	0.0959	0.0972	0.0986	0.0998	0.1010	0.1020
13	0.0782	0.0804	0.0824	0.0842	0.0860	0.0876	0.0892	0.0906	0.0919	0.0932
14	0.0677	0.0701	0.0724	0.0745	0.0775	0.0785	0.0801	0.0817	0.0832	0.0846
15	0.0575	0.0602	0.0628	0.0651	0.0673	0.0694	0.0713	0.0731	0.0748	0.0764
16	0.0476	0.0506	0.0534	0.0560	0.0584	0.0607	0.0628	0.0648	0.0662	0.0685
17	0.0379	0.0411	0.0442	0.0471	0.0497	0.0522	0.0546	0.0568	0.0588	0.0608
18	0.0283	0.0318	0.0352	0.0383	0.0412	0.0439	0.0465	0.0489	0.0511	0.0532
19	0.0188	0.0227	0.0263	0.0296	0.0328	0.0357	0.0385	0.0411	0.0436	0.0459
20	0.0094	0.0316	0.0175	0.0211	0.0245	0.0277	0.0307	0.0335	0.0361	0.0386
21	0.0000	0.0045	0.0087	0.0126	0.0163	0.0197	0.0229	0.0259	0.0288	0.0314
22	—	—	0.0000	0.0042	0.0081	0.0118	0.0153	0.0185	0.0215	0.0244
23	—	—	—	—	0.0000	0.0039	0.0076	0.0111	0.0143	0.0174
24	—	—	—	—	—	—	0.0000	0.0037	0.0071	0.0104
25	—	—	—	—	—	—	—	—	0.0000	0.0035

APPENDIX C

MODEL IMPLEMENTATION

To conduct an ERA case study, the user selects contaminants, receptors, and exposure pathways. The system will automatically generate the needed input information for user to complete the ERA case study, for example, the related media concentration. Subsequent to selecting and providing site data, the user can view and modify them before running the case study. Based on the input information, a model designed to implement exposure algorithms, will retrieve all the related parameters from the local database, calculate the result, and send it to the specified Microsoft Excel spreadsheet. Lastly, the output will be generated and the users can save them with their own file names.

For conducting an ERA case study, the interfaces are designed for selecting chemical, site, receptors and benchmarks These interfaces are shown by selecting the corresponding menus for the ERA interface and assist in conducting the ERA step by step as the following features.

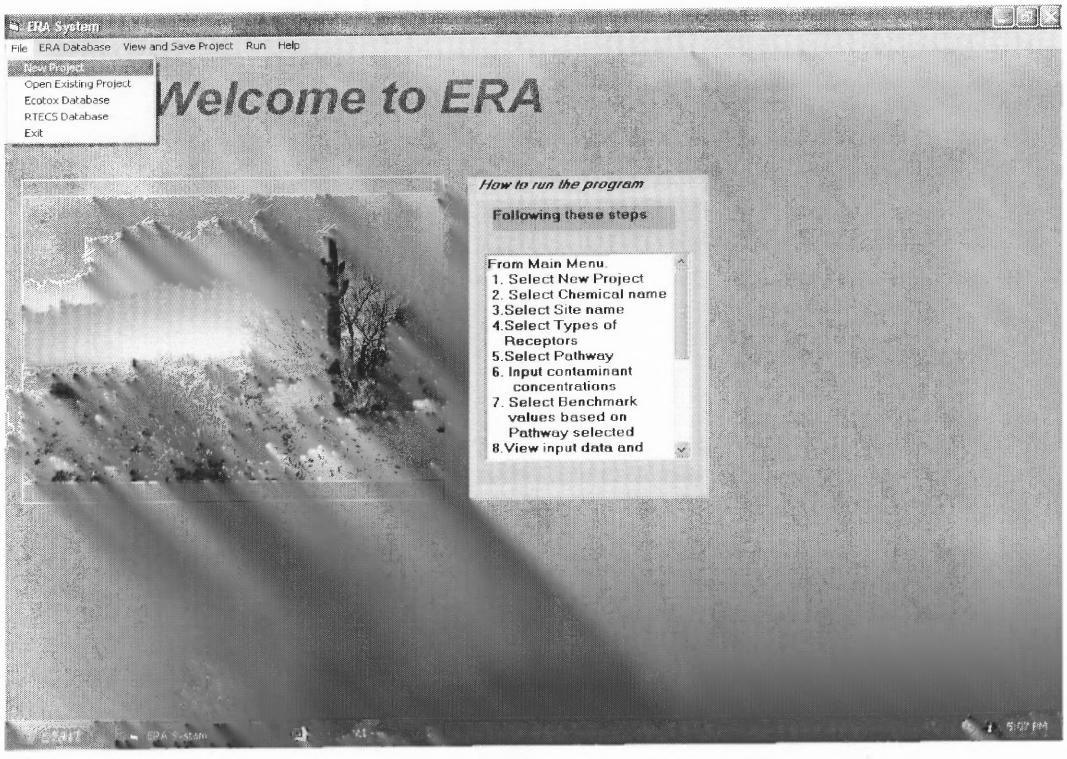


Figure C.1 ERA Interface.

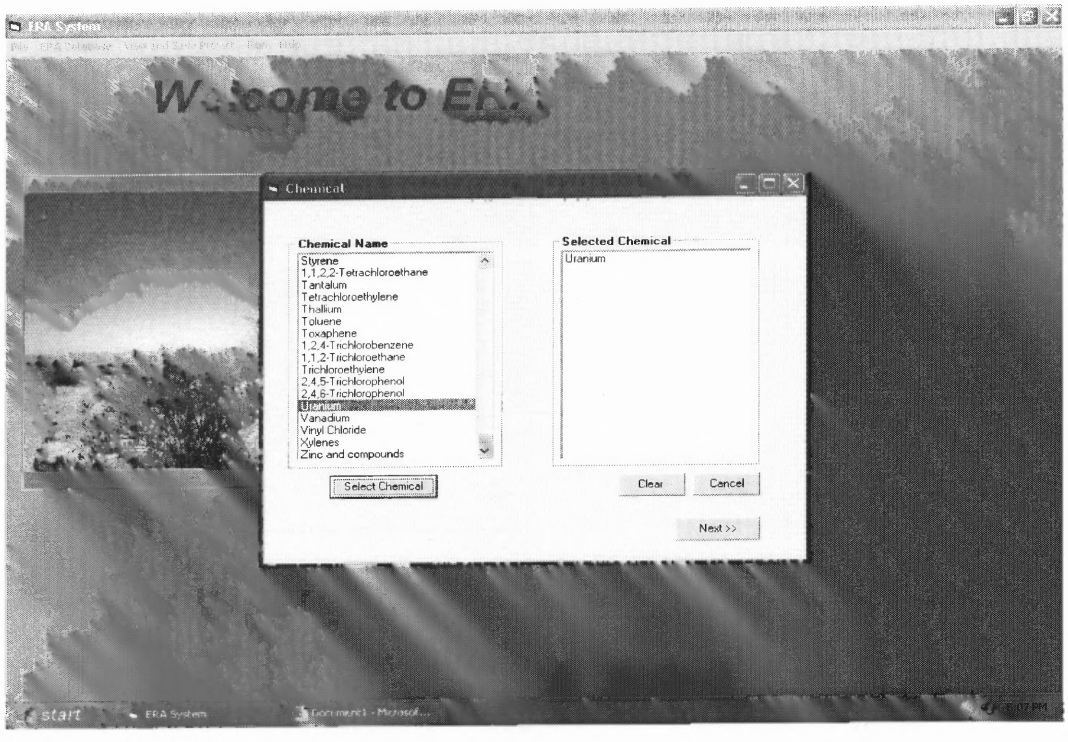


Figure C.2 Chemical Selected Interface.

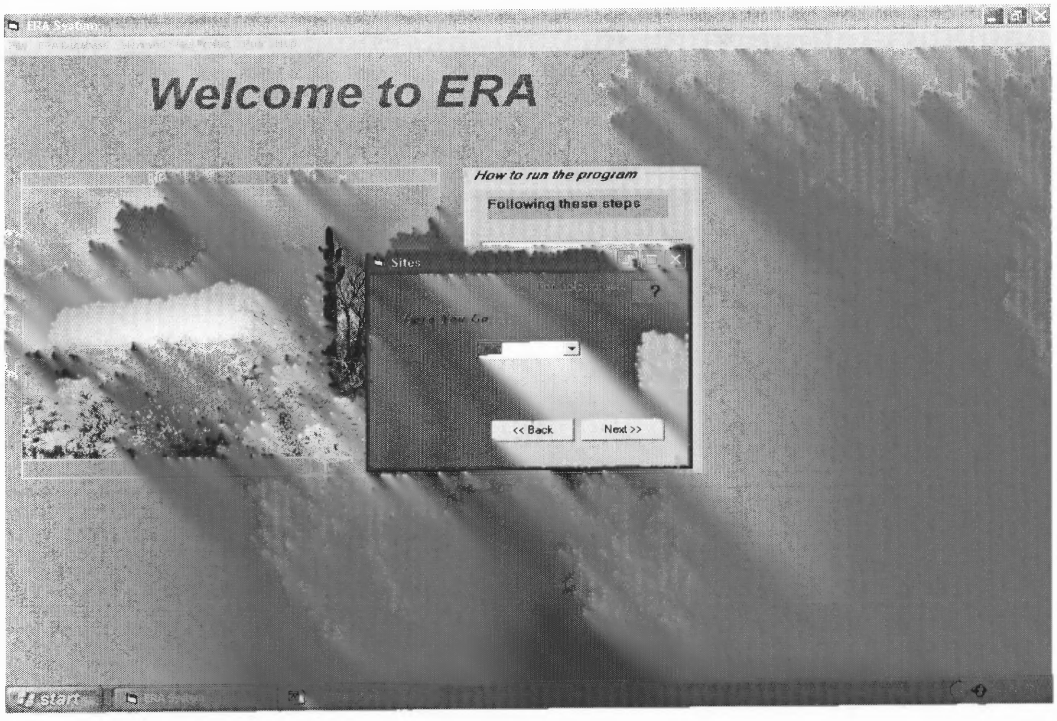


Figure C.3 Site selected interface.

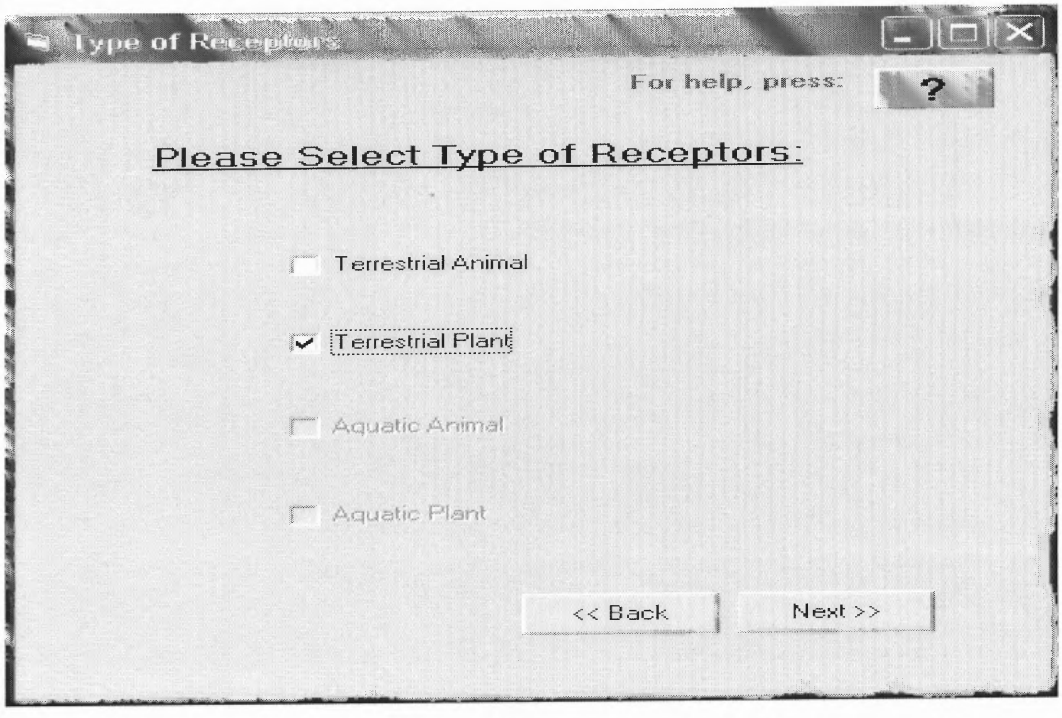


Figure C.4 Selecting type of receptors interface.

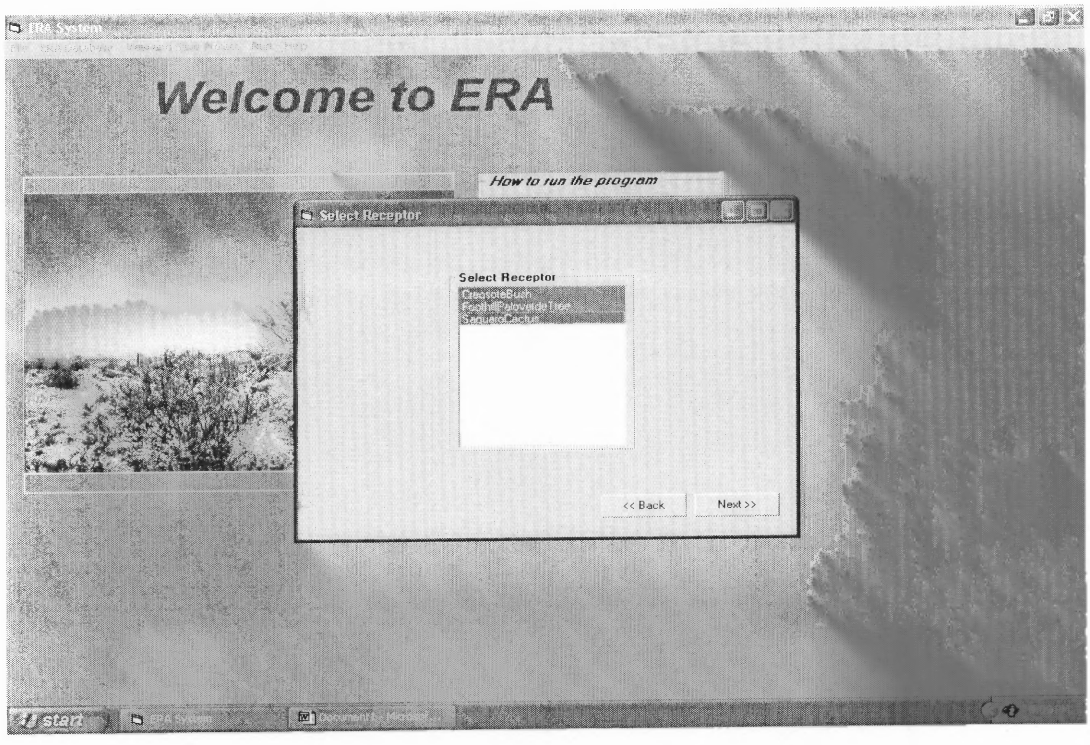


Figure C.5 Selected receptors interface.

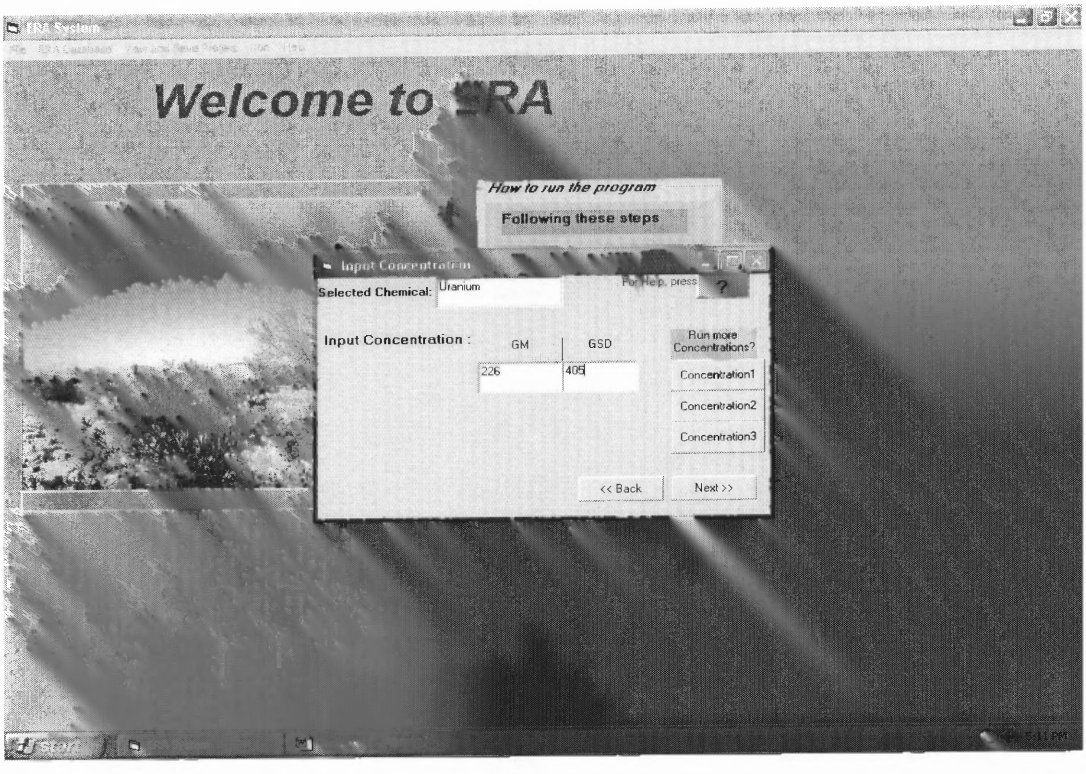


Figure C.6 Concentration input interface.

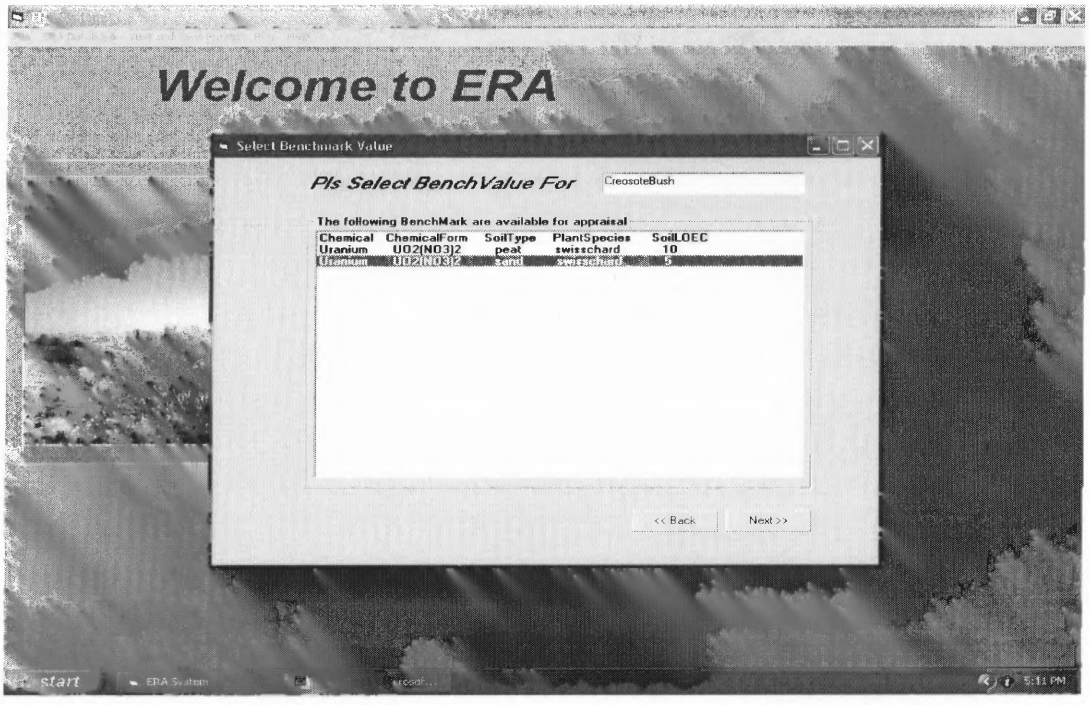


Figure C.7 Selecting benchmark value interface.

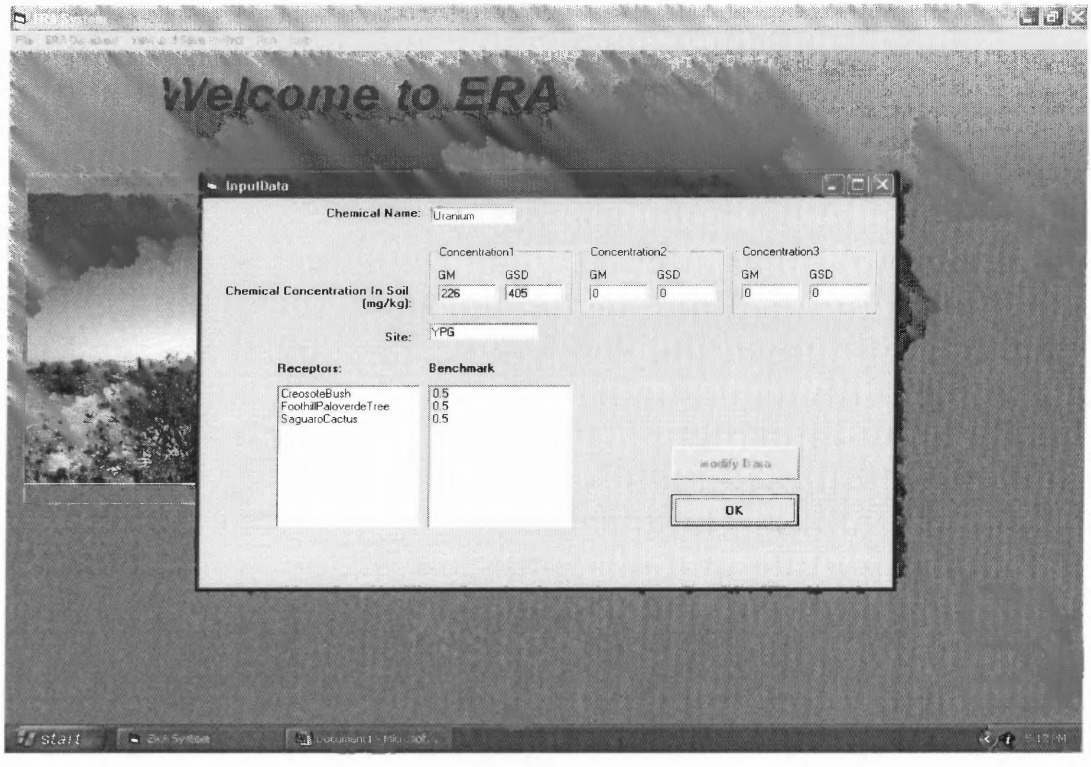


Figure C.8 Input data interface.

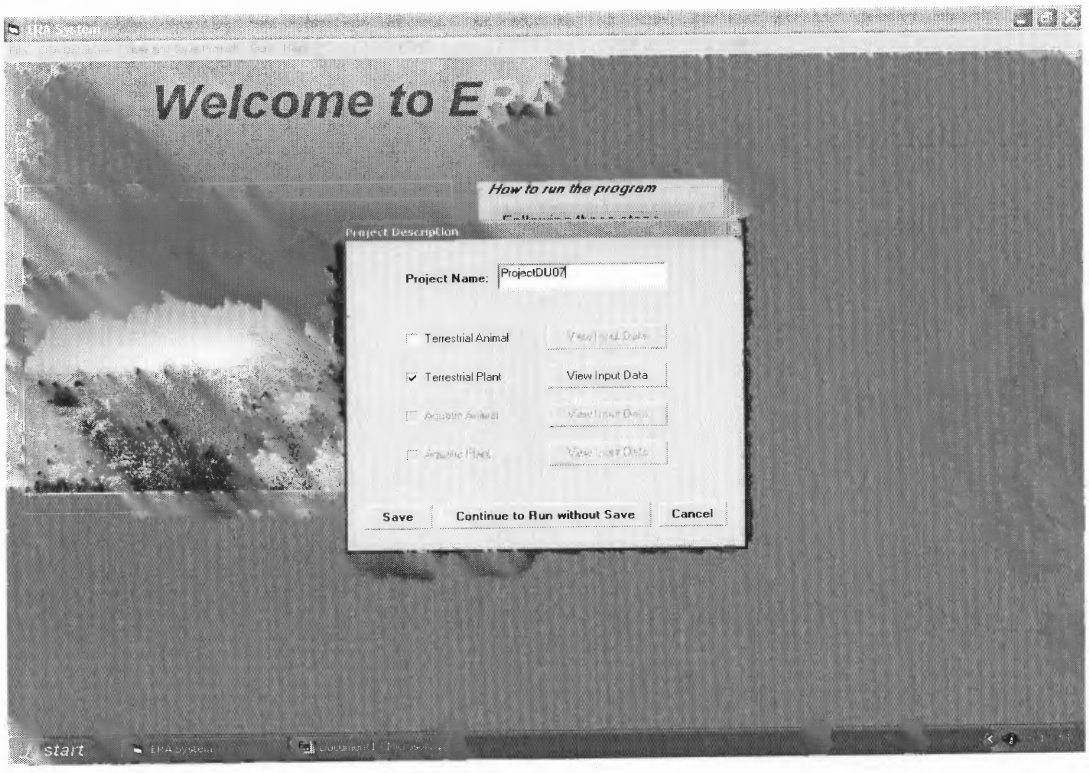


Figure C.9 Save project file interface.

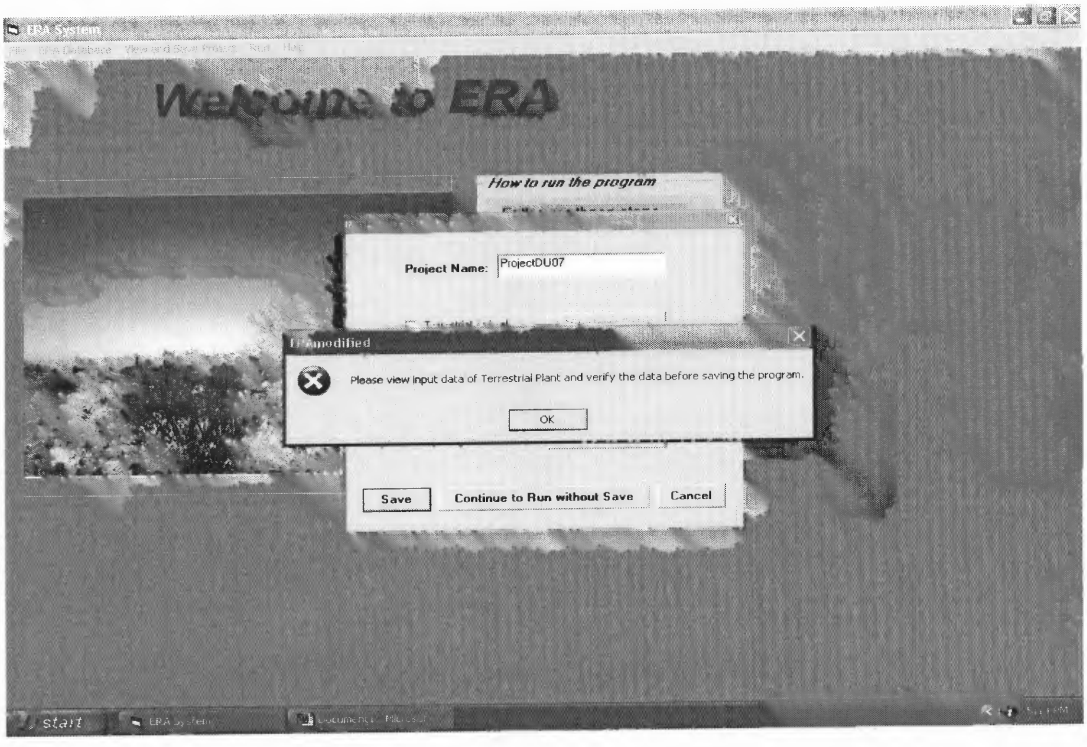


Figure C-10 Notified message Interface.

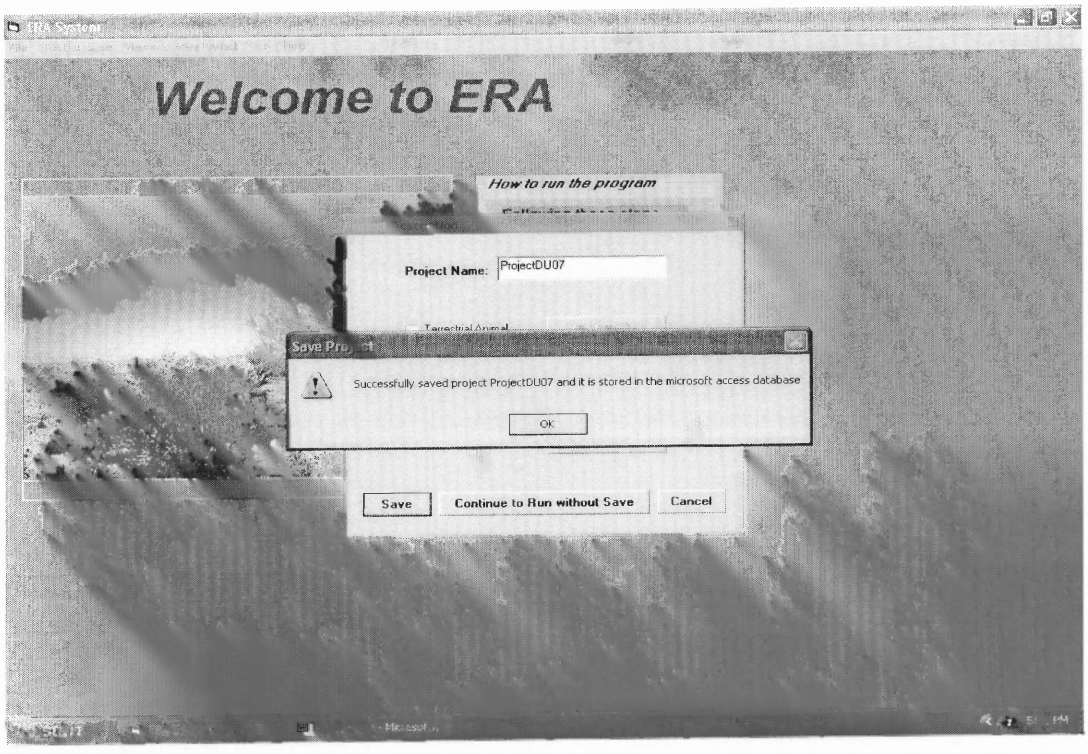


Figure C-11 Progressing status interface

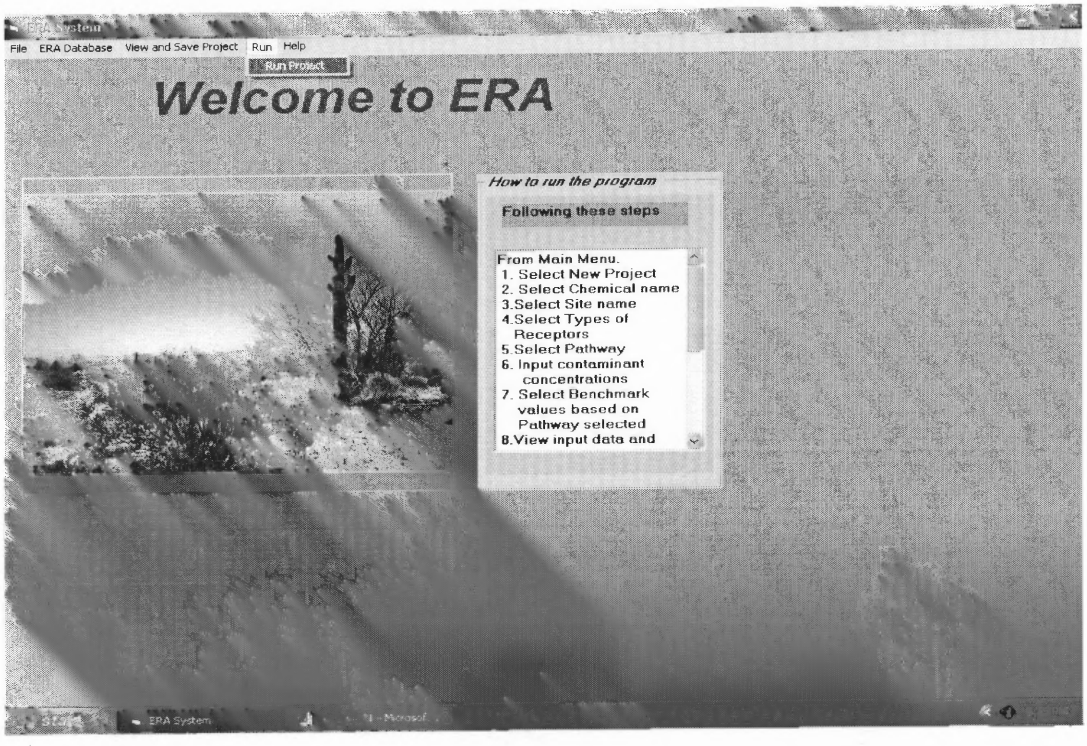
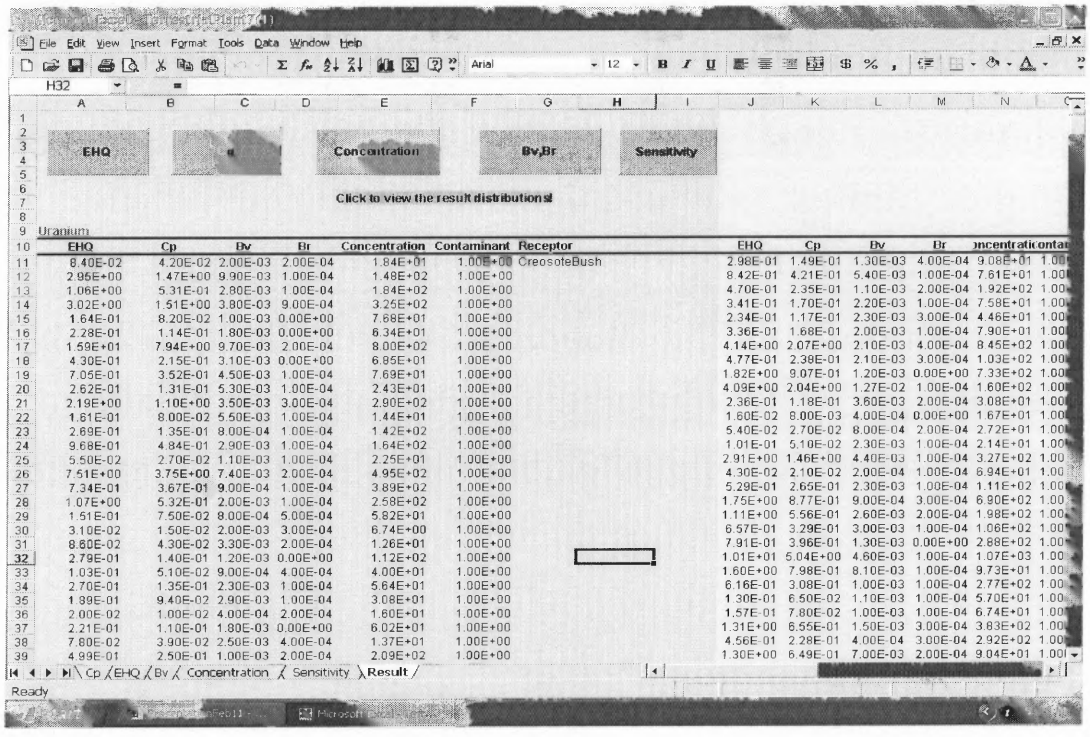


Figure C-13 Running program interface.



FigureC-14 Result Interface (Microsoft Excel).

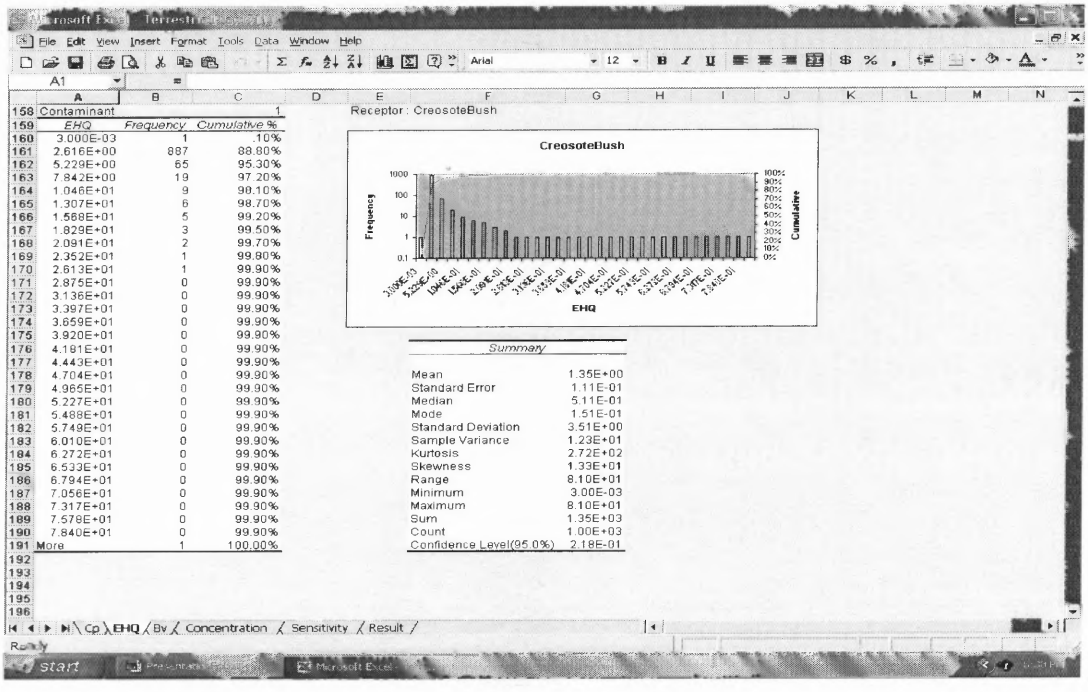


Figure C-15 Distribution Interface.

APPENDIX D

SAMPLING SITES

Figures D-1 to D-12 show sampling locations at YPG and APG sites

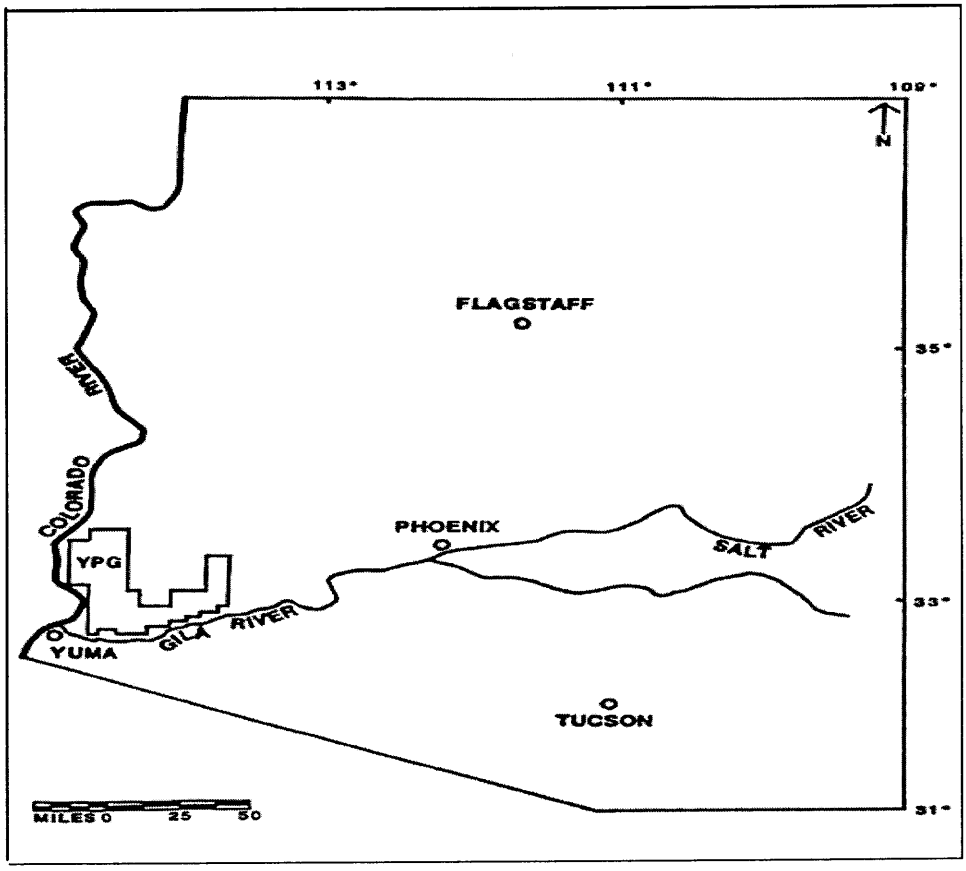


Figure D-1 Regional Map Depicting Yuma Proving Ground (U.S. Army YPG, 1999)

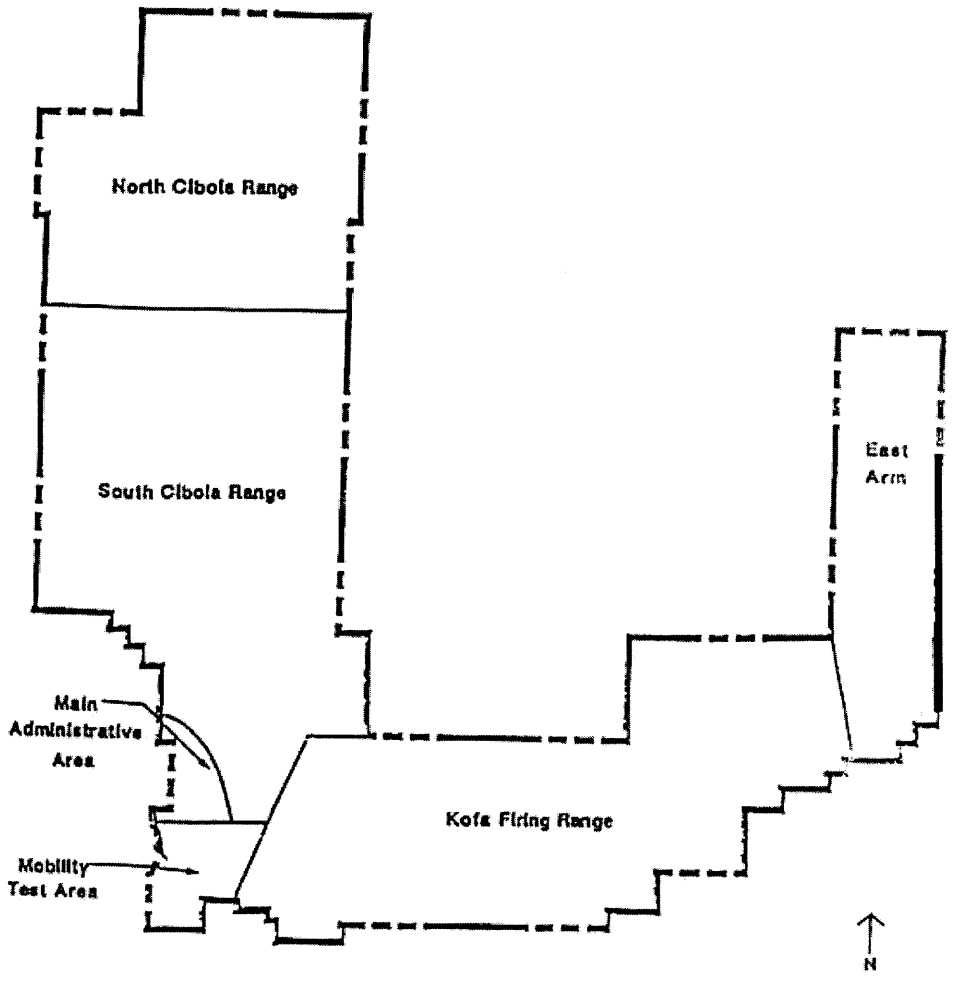


Figure D-2 General Site Map for Yuma Proving Ground (U.S. Army YPG, 1999).

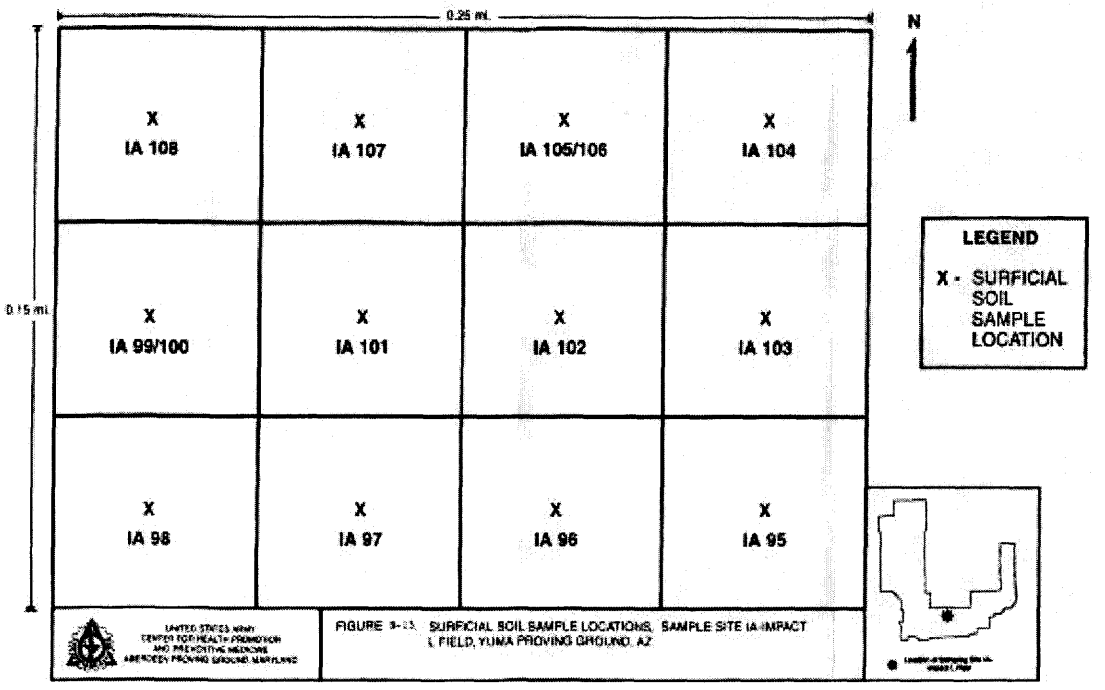


Figure D-3 Sample Site IA – Impact L Field, Yuma Proving Ground (U.S. Army YPG, 1999).

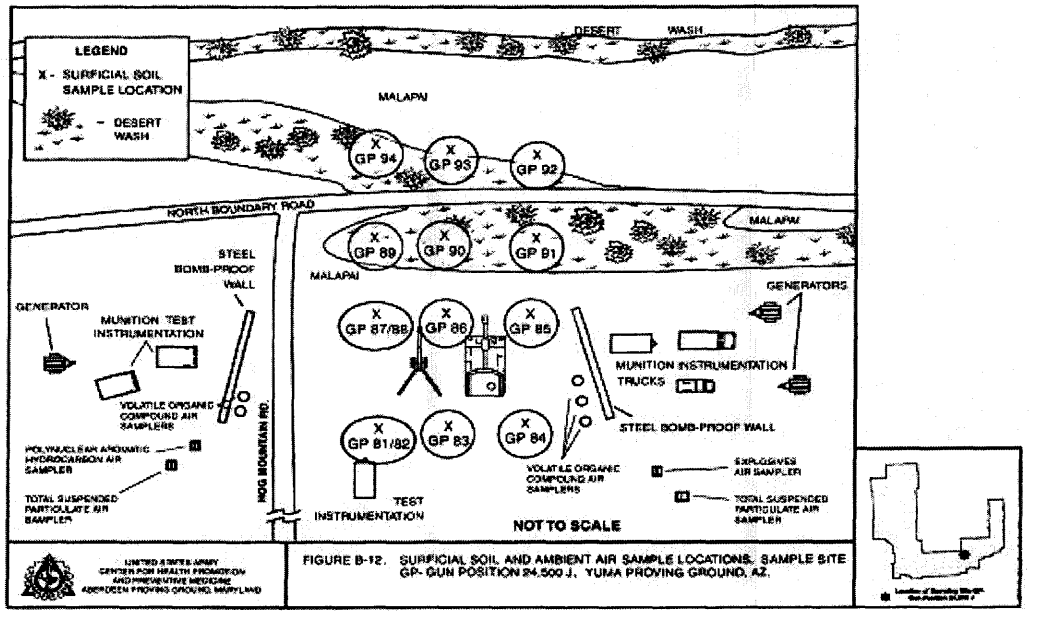


Figure D-4 Sample Site GP-Gun Position 24,500 J, Yuma Proving Ground (U.S. Army YPG, 1999).

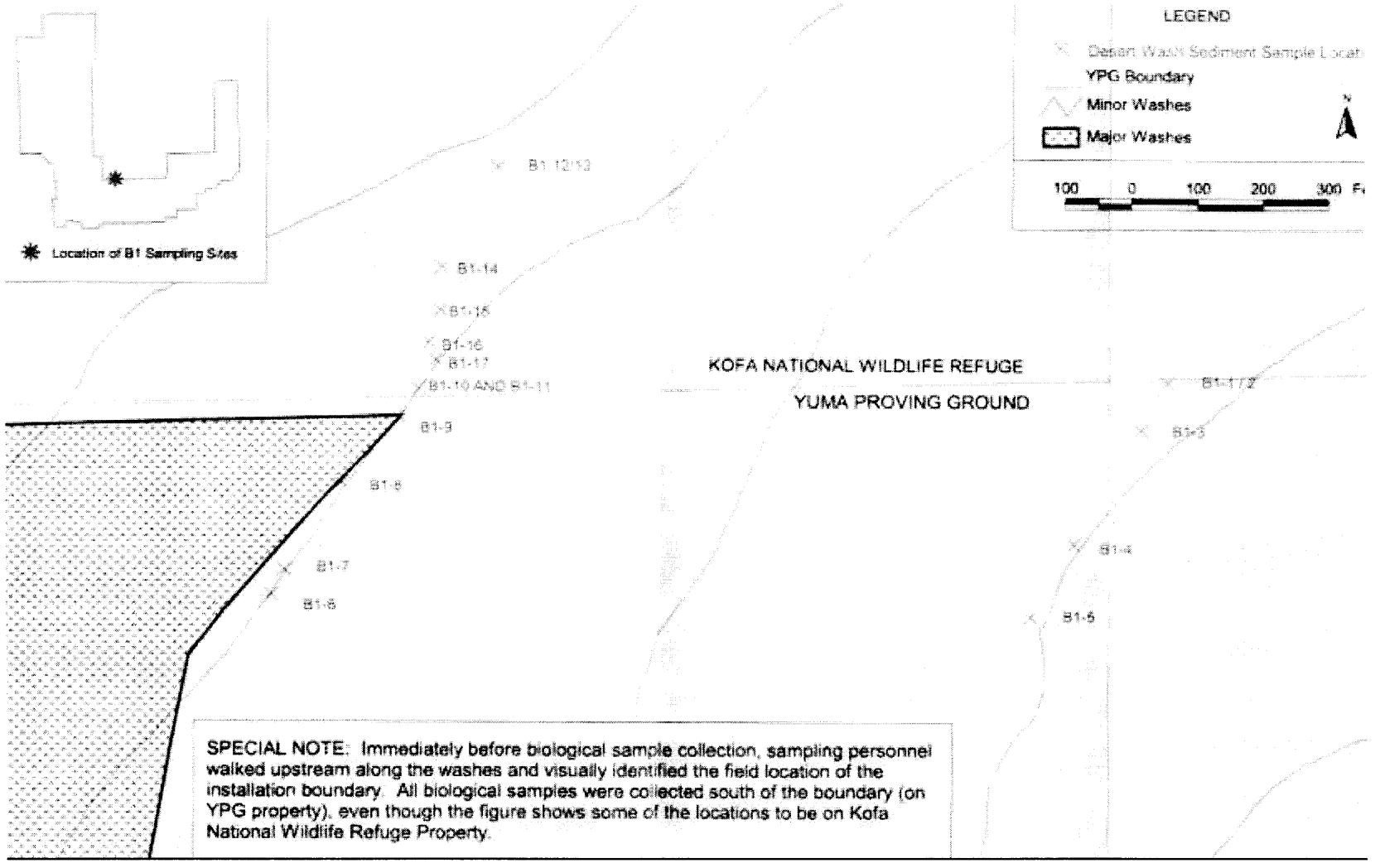


Figure D-5 Sample Site B1 – Impact Area Reference (Upstream) Site, Yuma Proving Ground (U.S. Army YPG, 1999).

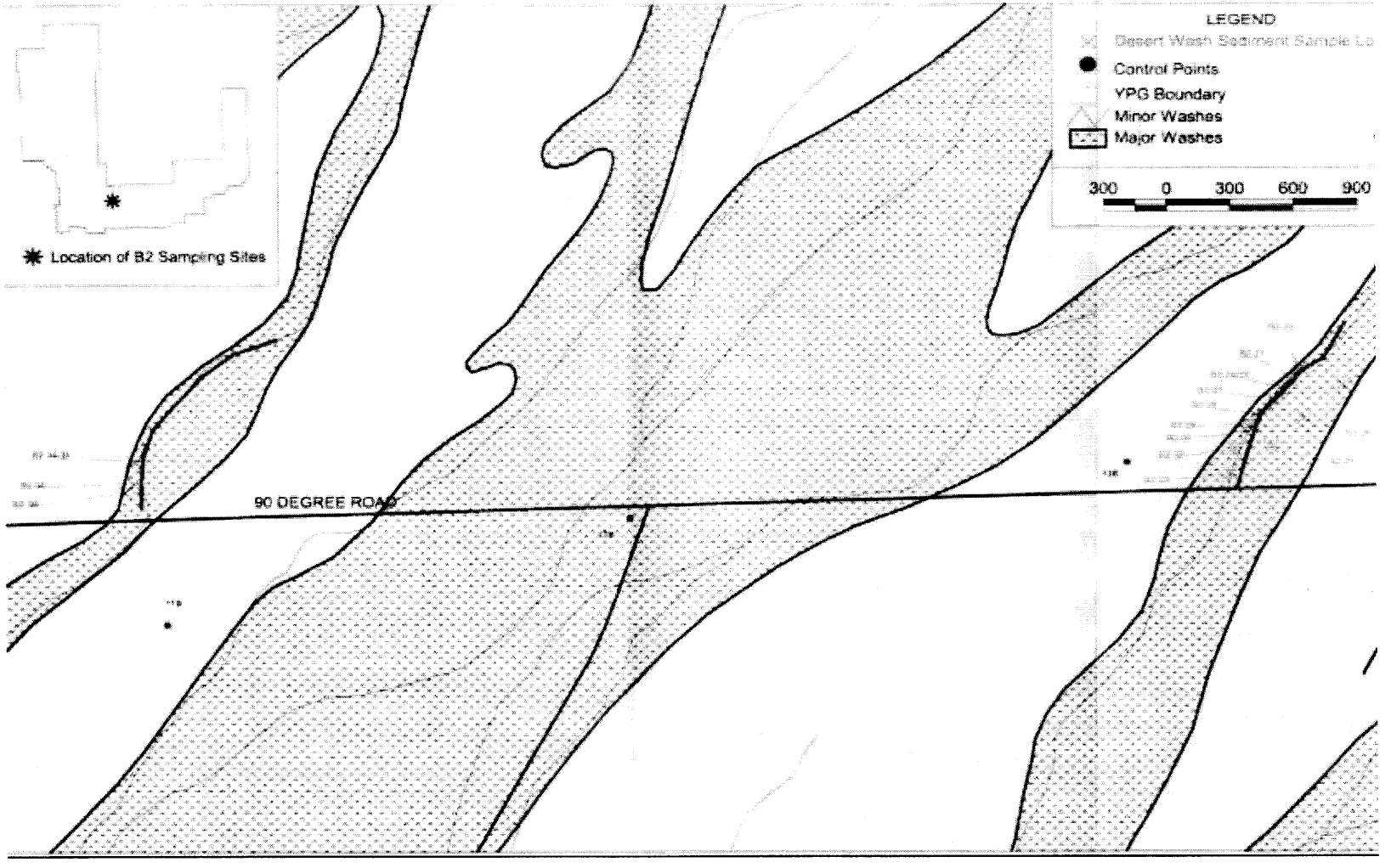


Figure D-6 Sample Site B2 – Impact Area (Downstream) Site, Yuma Proving Ground (U.S. Army YPG, 1999).

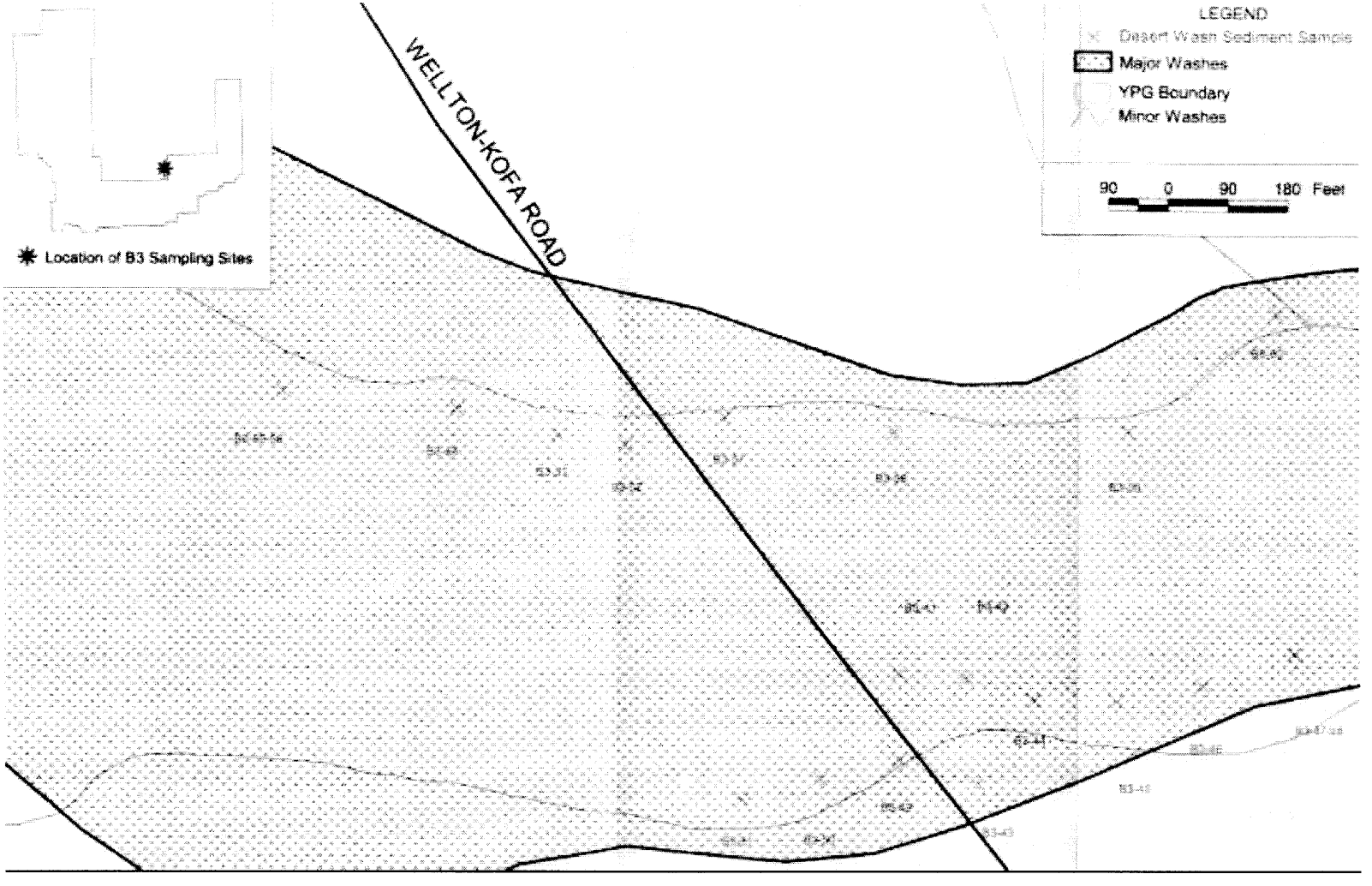


Figure D-7 Sample Site B3 – Extended High Explosive (HE) Impact Area (Long) Reference (Upstream) Site, Yuma Proving Ground (U.S. Army YPG, 1999).

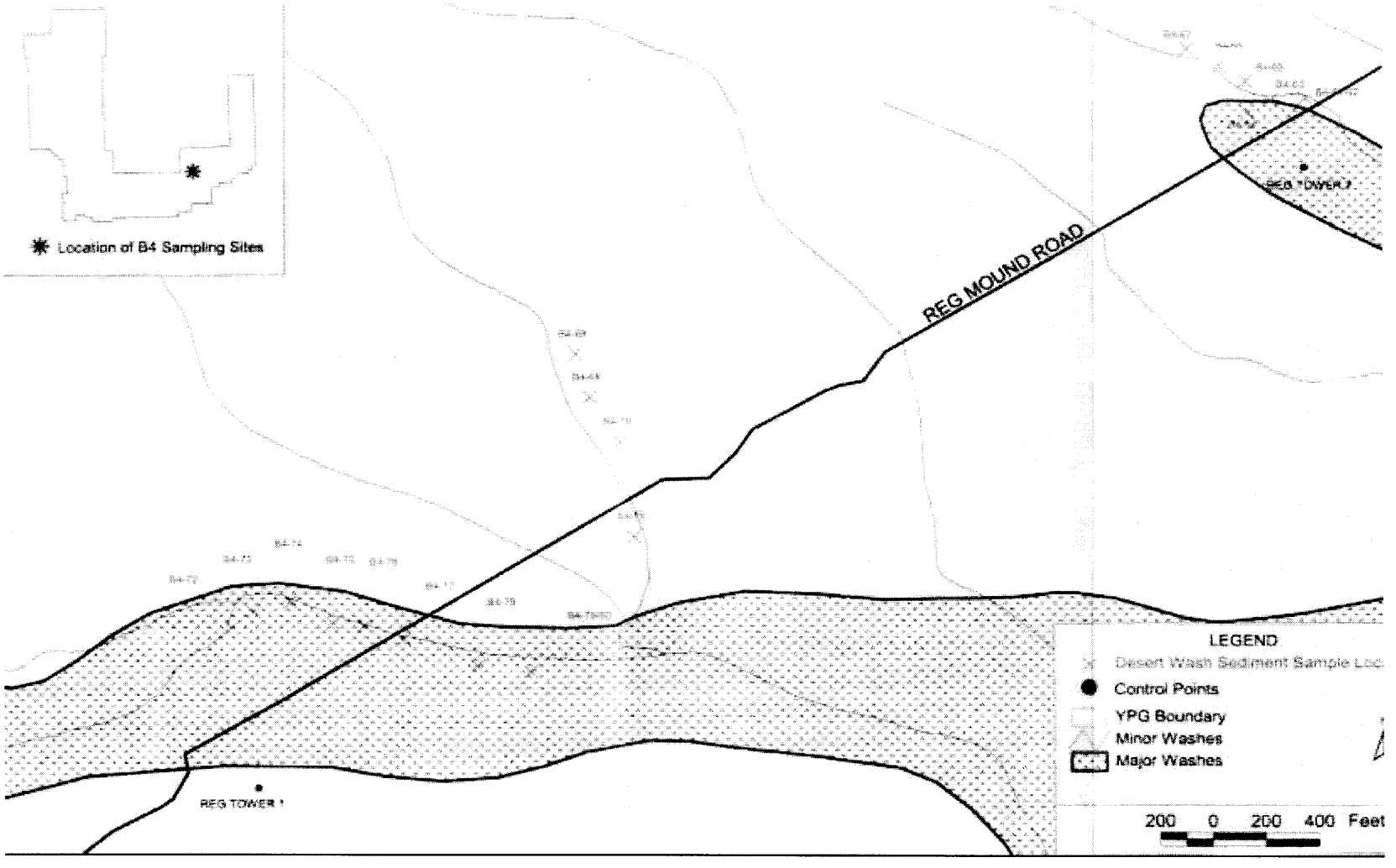


Figure D-8 Sample Site B4 – Extended High Explosive (HE) Impact Area (Long) Downstream Site, Yuma Proving Ground (U.S. Army YPG, 1999).

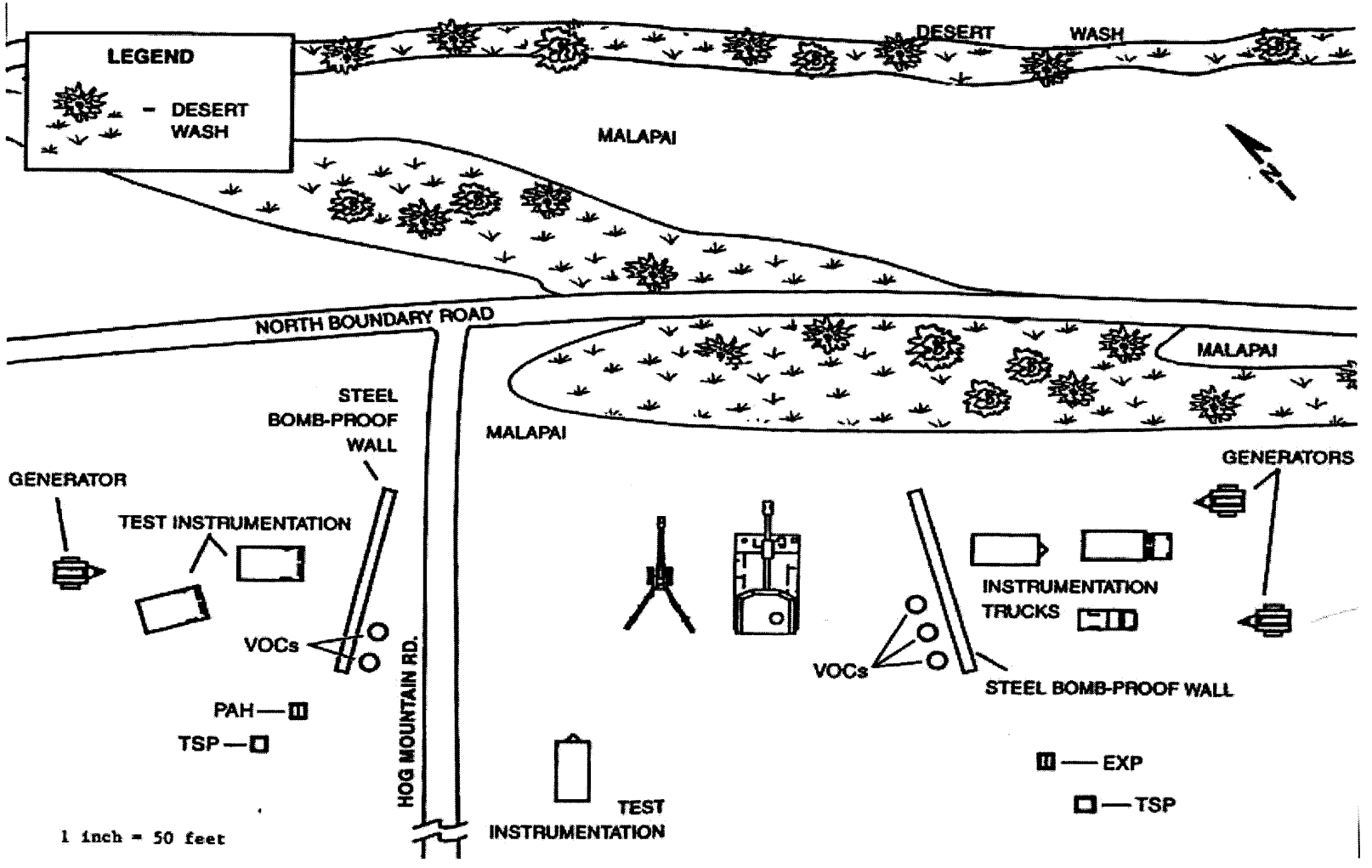


Figure D-9 Air Sampling Location at YPG (U.S. Army YPG, 1999).

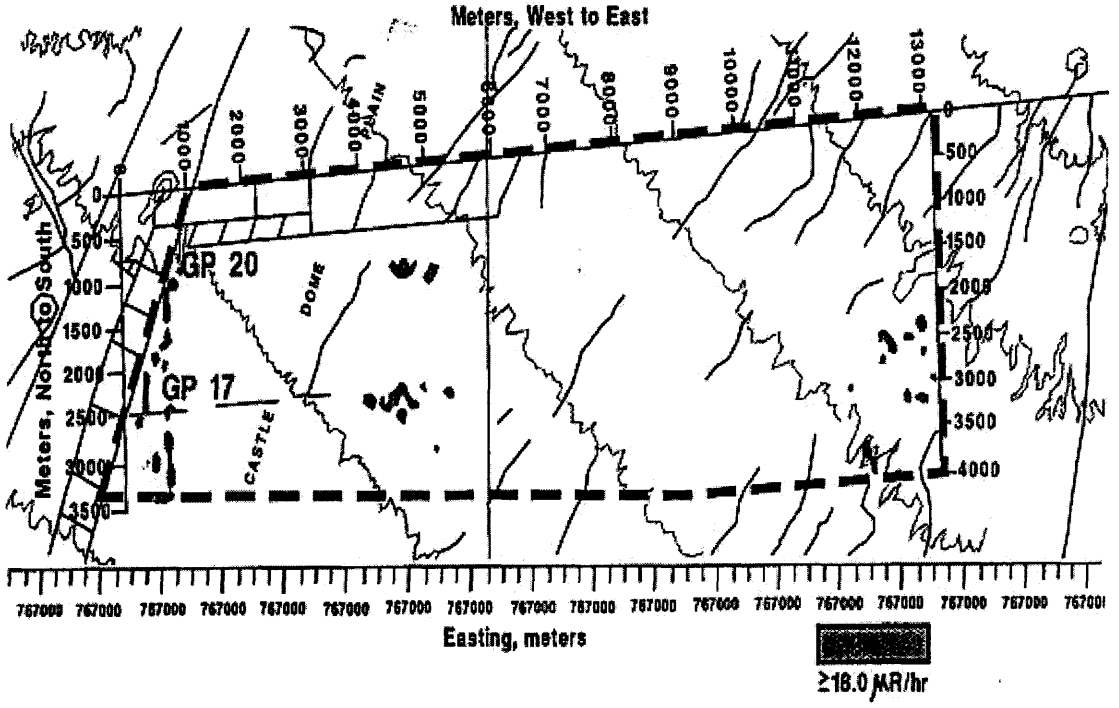
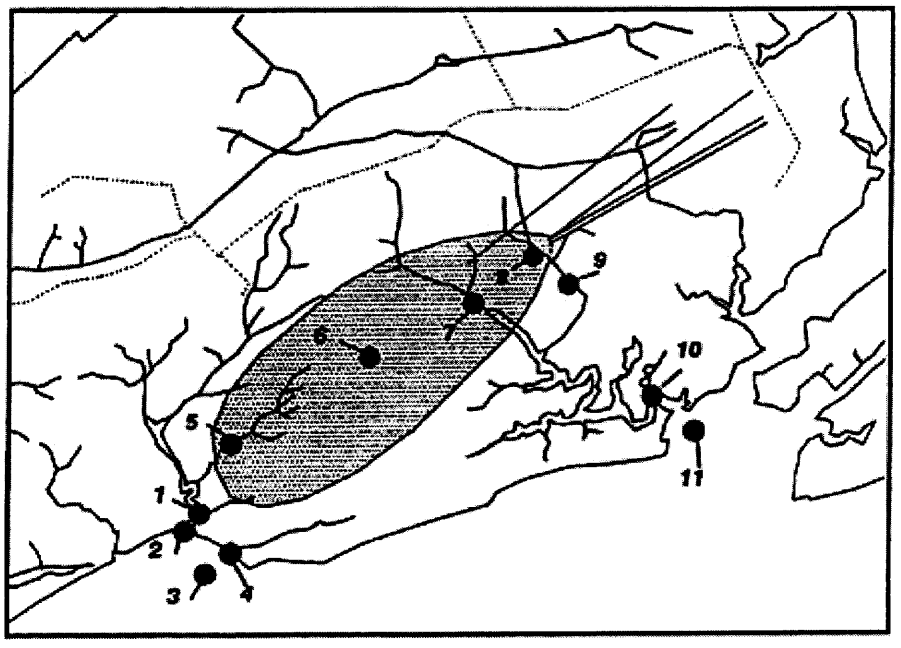


Figure D-10 GP 17a and GP 20 on the Kofa Firing Range at YPG (Oxenberg, 1997).



Map Identification Number	Site Name
1	Delph Creek #1
2	Delph Creek #2
3	Old Woman's Gut #2
4	Old Woman's Gut #1
5	Upper Delph Creek
6	DU Road
7	Upper Mosquito Creek
8	B3 Catch Box
9	B3 Creek
10	Mosquito Creek #1
11	Mosquito Creek #2

Figure D-11 Uranium Soil/Water Sampling locations at APG (Ebinger *et al.*, 1996).

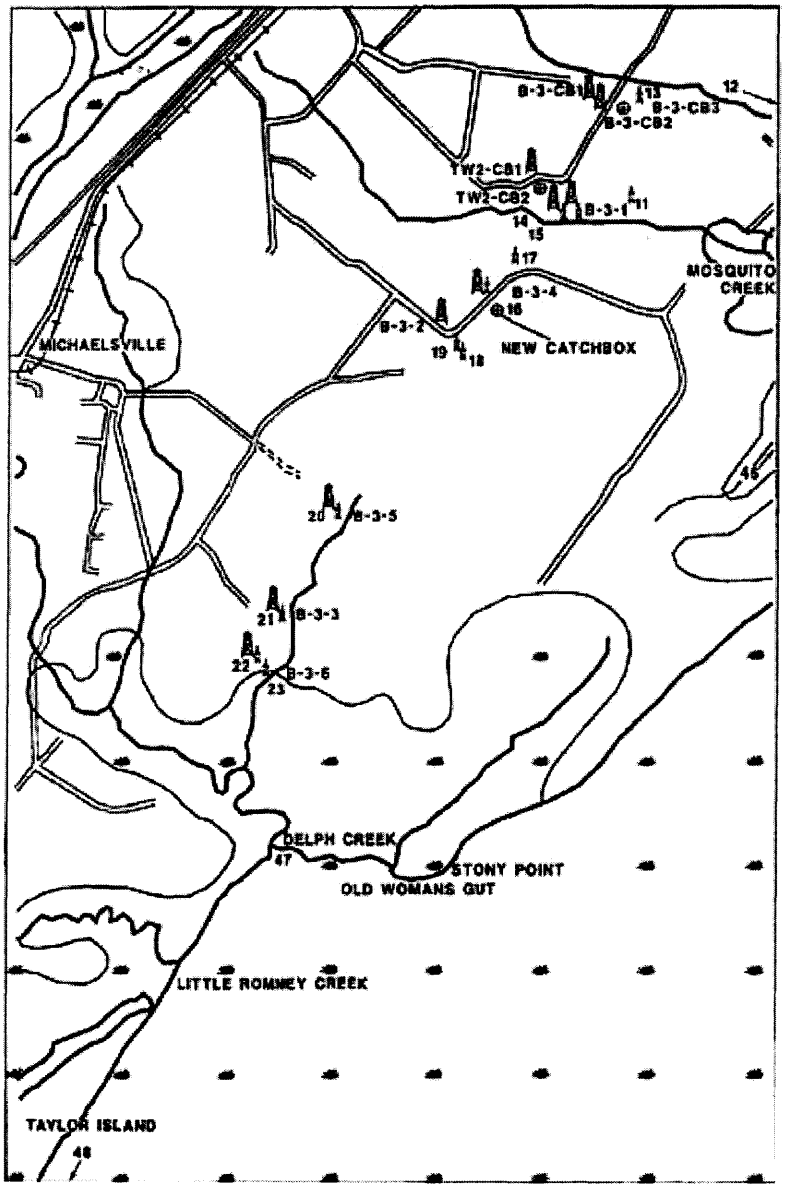


Figure D-12 Environmental radiation-monitoring points at APG (Oxenberg, 1997).

APPENDIX E

PARAMETER SENSITIVITY ANALYSIS RESULTS

Parameter sensitivity analysis results for each receptor in both APG and YPG sites are provided in the following Tables.

Table E-1 Sensitivity Analysis , Terrestrial Animals, APG

Pathway:Ingestion		Sensitivity(contribution to variance,%)		
Parameters	Definition	Lizards	Mallard	American kestrel
ECs	Contaminant concentration in soil/sediment	24.16	18.58	42.23
ECdw	Contaminant concentration in drinking water supply	24.32	18.70	42.50
IRf	Food ingestion rate	44.51	14.30	4.85
IRdw	Water ingestion rate	0.00	46.89	5.12
BW	Body weight	7.01	1.53	5.30
Q	Site use factor	0.00	0.00	0.00
W	Seasonality factor	0.00	0.00	0.00
FS	Mass fraction of soil/sediment in the diet	0.00	0.00	0.00
FR	Wet weight fraction of food item in the diet	0.00	0.00	0.00

Table E-1 Sensitivity Analysis , Terrestrial Animals, APG (Continued)

Pathway:Inhalation		Sensitivity(contribution to variance,%)		
Parameters	Definition	Lizards	Mallard	American kestrel
ECpar	Concentration of particulate-bound contaminant in air	17.23	48.73	40.61
ECvap	Concentration of volatilized contaminant in air	0.00	0.00	0.00
IRi	Inhalation rate	39.38	16.30	15.12
BW	Body weight	43.39	34.97	44.26
Q	Site use factor	0.00	0.00	0.00
W	Seasonality factor	0.00	0.00	0.00
Pathway: Dermal absorption				
ECs	Contaminant concentration in soil/sediment	67.14	86.52	82.75
BW	Body weight	19.47	7.15	10.38
SA	Surface area	13.40	6.33	6.87
Q	Site use factor	0.00	0.00	0.00
W	Seasonality factor	0.00	0.00	0.00
Pcs	Fraction of surface area in contact with soil per day	0.00	0.00	0.00
AF	Soil to skin adherence factor	0.00	0.00	0.00

Table E-1 Sensitivity Analysis , Terrestrial Animals, APG (Continued)

Pathway: Ingestion	Sensitivity(contribution to variance,%)				
Parameters	Eastern garter snake	Woodhouse's toad	Cottontail rabbit	White-footed mouse	White-tailed deer
ECs	35.54	31.13	32.81	26.57	26.34
ECdw	35.76	31.33	33.02	26.74	26.51
IRf	7.81	4.78	9.98	14.03	14.86
IRdw	0.00	0.00	11.21	14.55	15.65
BW	20.88	32.76	12.98	18.12	16.63
Q	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00
FS	0.00	0.00	0.00	0.00	0.00
FR	0.00	0.00		0.00	0.00
Pathway: Inhalation					
ECpar	12.54	6.53	17.41	10.69	11.35
ECvap	0.00	0.00	0.00	0.00	0.00
IRi	23.46	33.79	22.76	25.97	26.42

Table E-1 Sensitivity Analysis , Terrestrial Animals, APG (Continued)

Pathway: Inhalation	Sensitivity(contribution to variance,%)				
Parameters	Eastern garter snake	Woodhouse's toad	Cottontail rabbit	White-footed mouse	White-tailed deer
BW	64.01	59.69	59.83	63.34	62.23
Q	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00
Pathway: Dermal absorption					
ECs	62.30	45.34	60.80	47.94	47.55
BW	36.61	47.72	24.06	32.69	30.02
SA	1.09	6.94	15.14	19.37	22.43
Q	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00
Pcs	0.00	0.00	0.00	0.00	0.00
AF	0.00	0.00	0.00	0.00	0.00

Table E-1 Sensitivity Analysis , Terrestrial Animals, APG (Continued)

Pathway:Ingestion	Sensitivity(contribution to variance,%)			
Parameters	Beaver	Indiana bat	Bald eagle	Barred owl
ECs	31.44	29.17	42.29	41.27
ECdw	31.64	29.36	42.56	41.53
IRf	10.92	9.26	4.31	3.07
IRdw	12.04	16.73	4.09	6.02
BW	13.96	15.47	6.75	8.12
Q	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00
FS	0.00	0.00	0.00	0.00
FR	0.00	0.00	0.00	0.00
Pathway: Inhalation				
ECpar	15.90	13.81	34.40	29.03
ECvap	0.00	0.00	0.00	0.00
IRi	22.74	22.56	17.90	21.36

Table E-1 Sensitivity Analysis , Terrestrial Animals, APG (Continued)

Pathway: Inhalation	Sensitivity(contribution to variance,%)			
Parameters	Beaver	Indiana bat	Bald eagle	Barred owl
BW	61.36	63.62	47.70	49.61
Q	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00
Pathway: Dermal absorption				
ECs	57.63	54.40	79.65	71.77
BW	25.60	28.84	12.71	14.12
SA	16.77	16.76	7.64	14.12
Q	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00
Pcs	0.00	0.00	0.00	0.00
AF	0.00	0.00	0.00	0.00

Table E-2 Sensitivity Analysis, Aquatic Species ,APG

Aquatic Animals		Sensitivity(Contribution to variance,%)			
Parameters	Definition	MountainWhitefish	PacificLamprey	RainbowTrout (adults)	WhiteSturgeon
BCF	Bioconcentration factor	1.31	1.35	1.28	1.33
Concentration	Contaminant concentration in media	98.69	98.65	98.72	98.67
Aquatic Plants		Periphyton	Phytoplankton	Watermillfoil	
BCF	Bioconcentration factor	0.08	0.06	0.08	
Concentration	Contaminant concentration in media	99.92	99.94	99.92	

Table E-3 Sensitivity Analysis, Terrestrial Plant, APG

Terrestrial Plants		Sensitivity(Contribution to variance,%)		
Parameters	Definition	Rushes	Slender blue flag	Fern
Bv	Bioconcentration factor for nonvegetative plant parts	44.28	46.67	46.97
Br	Bioconcentration factor for vegetative plant parts	45.59	43.98	42.83
Concentration	Contaminant concentration	10.13	9.35	10.20

Table E-4 Sensitivity Analysis , Terrestrial Animals, YPG

	Pathway: Ingestion	Sensitivity(contribution to variance,%)		
Parameters	Definition	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike
ECs	Contaminant concentration in soil/sediment	32.35	28.50	42.65
ECdw	Contaminant concentration in drinking water supply	34.25	30.17	45.15
IRf	Food ingestion rate	10.06	9.48	2.84
IRdw	Water ingestion rate	11.13	16.02	3.07
BW	Body weight	12.22	15.83	6.28
Q	Site use factor	0.00	0.00	0.00
W	Seasonality factor	0.00	0.00	0.00
FS	Mass fraction of soil/sediment in the diet	0.00	0.00	0.00
FR	Wet weight fraction of food item in the diet	0.00	0.00	0.00
	Pathway: Inhalation			
ECpar	Concentration of particulate-bound contaminant in air	18.06	13.29	10.32
ECvap	Concentration of volatilized contaminant in air	0.00	0.00	0.00
IRi	Inhalation rate	23.06	23.04	76.57

Table E-4 Sensitivity Analysis , Terrestrial Animals, YPG(Continued)

	Pathway: Inhalation	Sensitivity(contribution to variance,%)		
Parameters	Definition	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike
BW	Body weight	58.88	63.67	13.11
Q	Site use factor	0.00	0.00	0.00
W	Seasonality factor	0.00	0.00	0.00
	Pathway: Dermal absorption			
ECs	Contaminant concentration in soil/sediment	61.93	55.14	80.82
BW	Body weight	23.39	30.62	11.90
SA	Surface area	14.69	14.24	7.28
Q	Site use factor	0.00	0.00	0.00
W	Seasonality factor	0.00	0.00	0.00
Pcs	Fraction of surface area in contact with soil per day	0.00	0.00	0.00
AF	Soil to skin adherence factor	0.00	0.00	0.00

Table E-4 Sensitivity Analysis , Terrestrial Animals, YPG(Continued)

Pathway: Ingestion	Sensitivity (contribution to variance,%)				
Parameters	Mexican spotted owl	Desert tortoises	Kit fox	Mule deer	Sonora whipsnake
ECs	43.68	28.47	38.06	31.21	20.89
ECdw	46.25	30.14	40.29	33.04	22.11
IRf	3.28	38.44	0.15	10.70	46.24
IRdw	3.20	0.00	10.01	11.59	0.00
BW	3.59	2.95	11.49	13.46	10.76
Q	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00
FS	0.00	0.00	0.00	0.00	0.00
FR	0.00	0.00		0.00	0.00
Pathway: Inhalation					
ECpar	49.63	36.34	21.37	16.21	10.80
ECvap	0.00	0.00	0.00	0.00	0.00
IRi	15.20	31.13	22.94	23.46	41.18
BW	35.17	32.53	55.69	60.33	48.02
Q	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00
Pathway: Dermal absorption					
ECs	86.97	89.14	66.82	59.16	65.27
BW	7.14	9.25	20.18	25.52	33.62
SA	5.88	1.61	13.00	15.32	1.12
Q	0.00	0.00	0.00	0.00	0.00
W	0.00	0.00	0.00	0.00	0.00
Pcs	0.00	0.00	0.00	0.00	0.00
AF	0.00	0.00	0.00	0.00	0.00

Table E-4 Sensitivity Analysis , Terrestrial Animals, YPG(Continued)

Pathway: Ingestion	Sensitivity (contribution to variance,%)		
Parameters	Desert spiny Lizards	Cactus mouse	Gambel's quail
ECs	39.15	32.58	36.64
ECdw	41.45	34.49	38.79
IRf	7.79	5.92	7.07
IRdw	0	10.96	7.42
BW	11.61	16.05	10.07
Q	0	0	0
W	0	0	0
FS	0	0	0
FR	0	0	0
Pathway: Inhalation			
ECpar	17	7.66	23
ECvap	0	0	0
IRi	39.49	59.79	22.45
BW	43.51	32.55	54.55
Q	0	0	0
W	0	0	0
Pathway: Dermal absorption			
ECs	66.63	41.13	68.17
BW	19.77	20.26	18.74
SA	13.6	38.61	13.09
Q	0	0	0
W	0	0	0
Pcs	0	0	0
AF	0	0	0

Table E-5 Sensitivity Analysis, Terrestrial Plant, YPG

Parameters	Definition	Sensitivity(Contribution to variance,%)		
		CreosoteBush	FoothillPaloverdeTree	SaguaroCactus
Bv	Bioconcentration factor for nonvegetative plant parts	44.28	46.67	46.97
Br	Bioconcentration factor for vegetative plant parts	45.59	43.98	42.83
Concentration	Contaminant concentration	10.13	9.35	10.2

APPENDIX F

DISTRIBUTION RESULTS

The following figures show the risk distributions for all receptors in both APG and YPG sites.

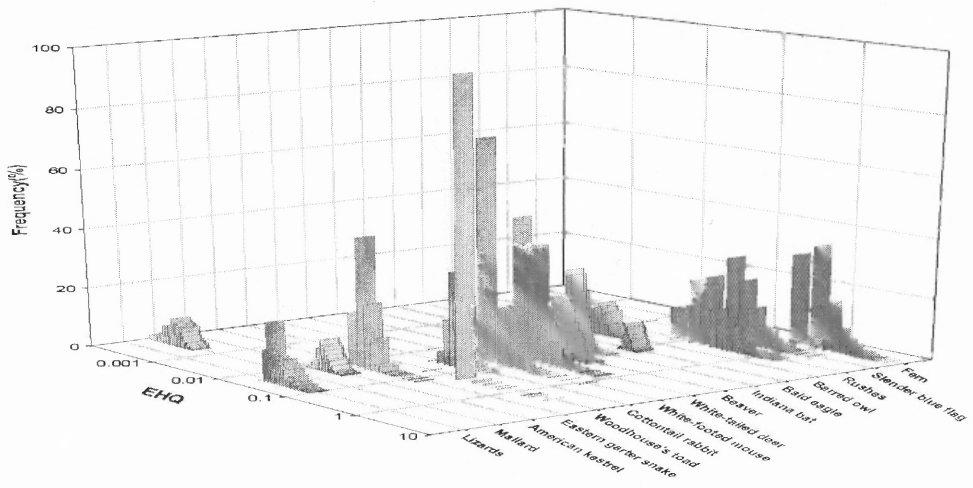


Figure F-1 EHQ Distribution (Cr) for terrestrial animal and plant receptors at APG.

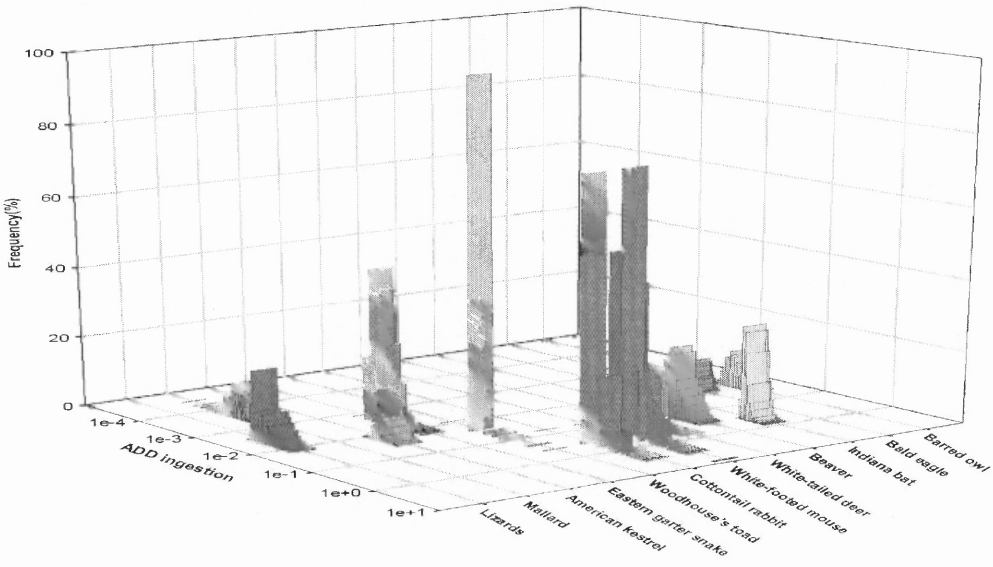
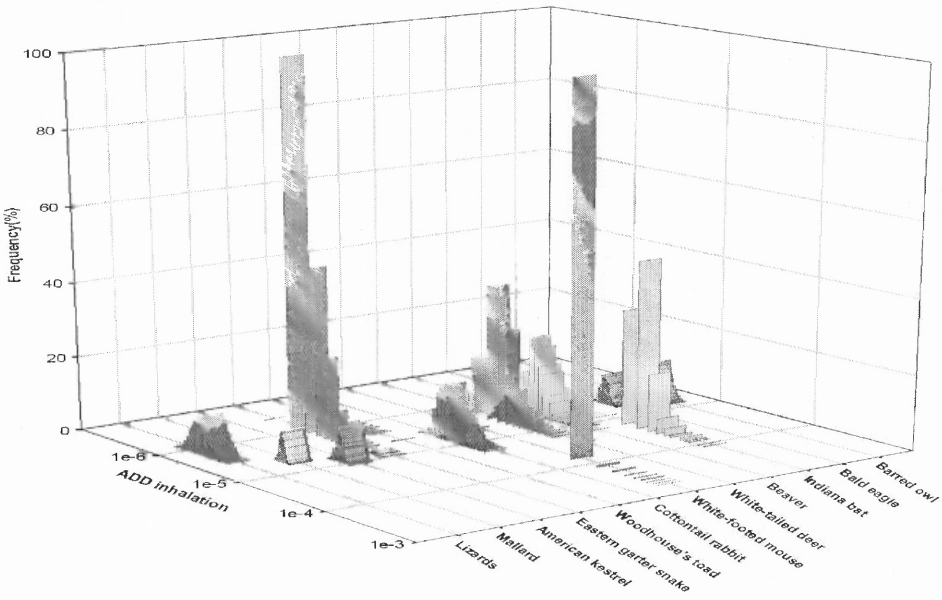


Figure F-2 ADD Ingestion Distribution (Cr) for Terrestrial Animals at APG



FigureE-3 ADD Inhalation Distribution (Cr) for Terrestrial Animals at APG.

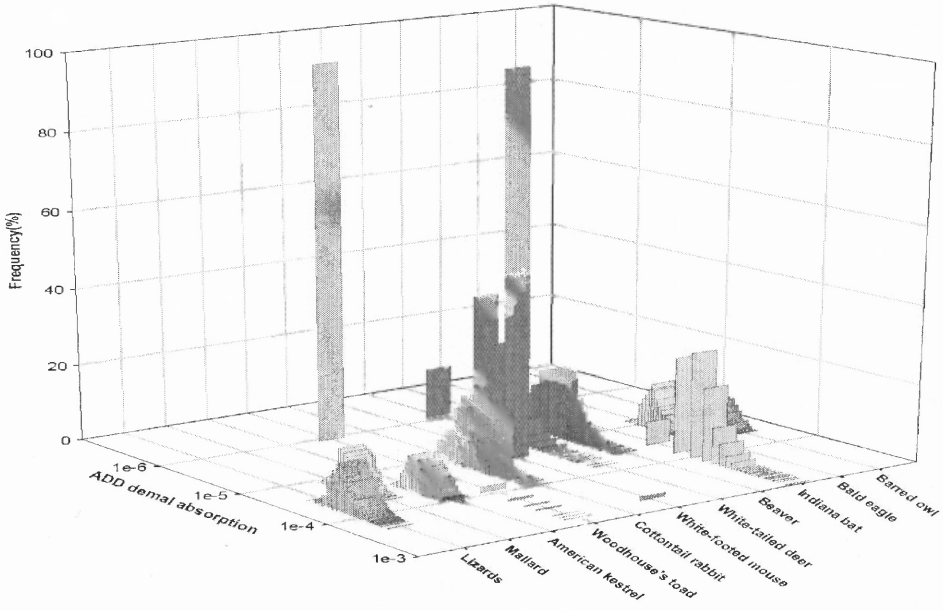


Figure F-4 ADD Dermal Absorption Distribution (Cr) for Terrestrial Animals at APG.

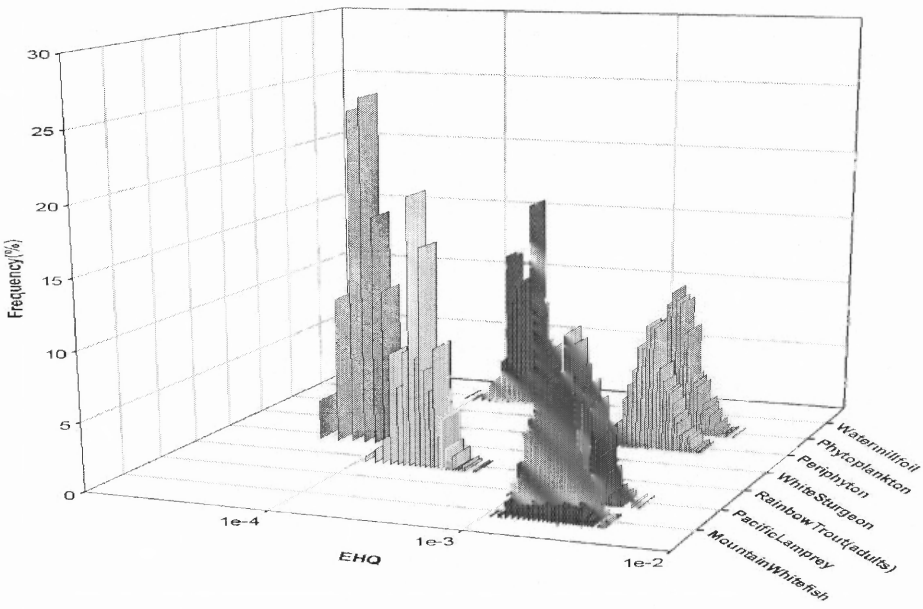


Figure F-5 EHQ Distribution (Cr) for Aquatic Species at APG.

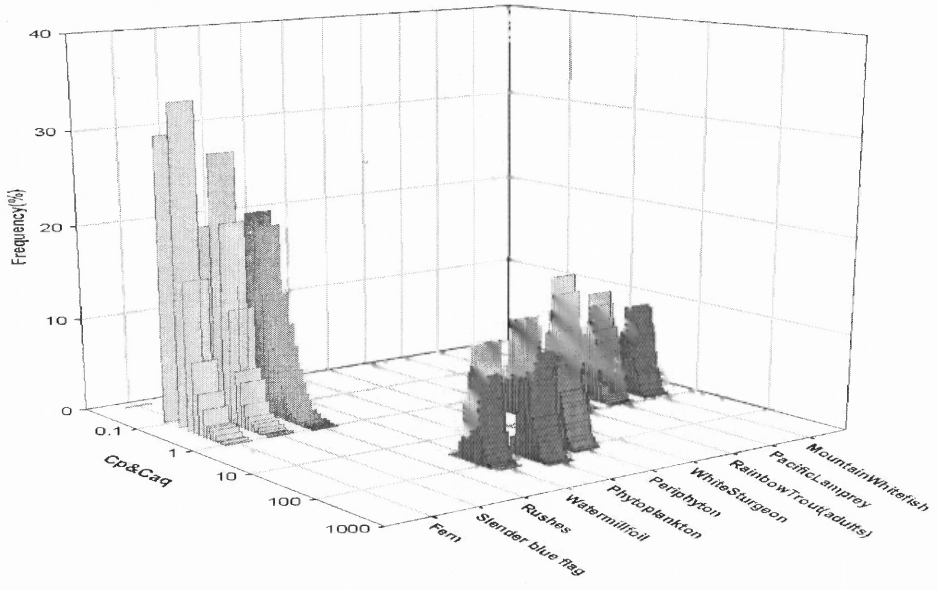


Figure F- 6 Cp and Caq Distribution (Cr) for Terrestrial Plants and Aquatic Species at APG.

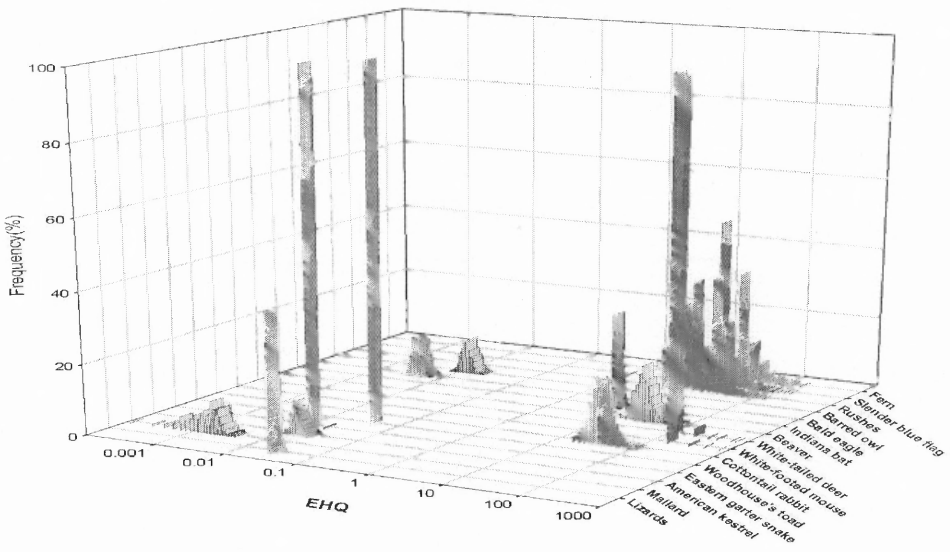


Figure F-7 EHQ Distribution (Mo) for Terrestrial Animal and Plant Receptors at APG.

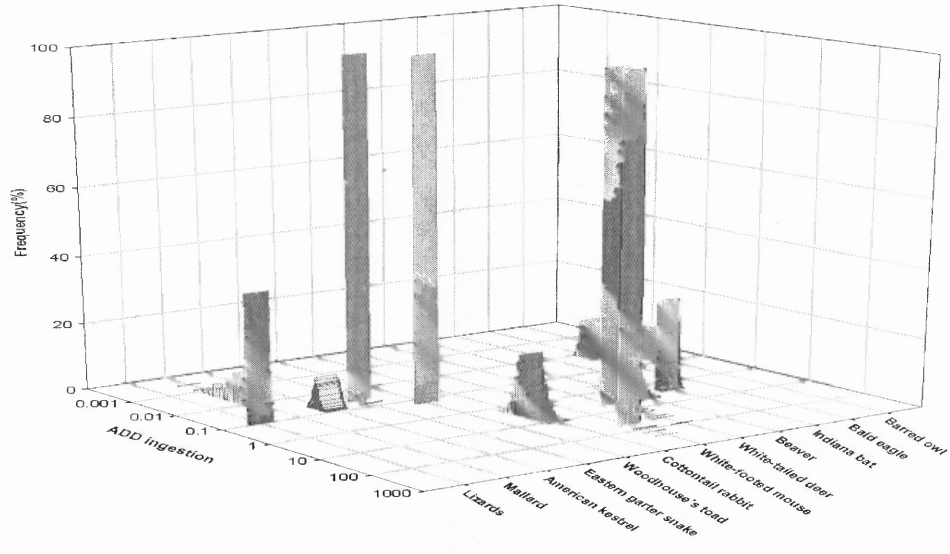


Figure F-8 ADD Ingestion Distribution (Mo) for Terrestrial Animals at APG.

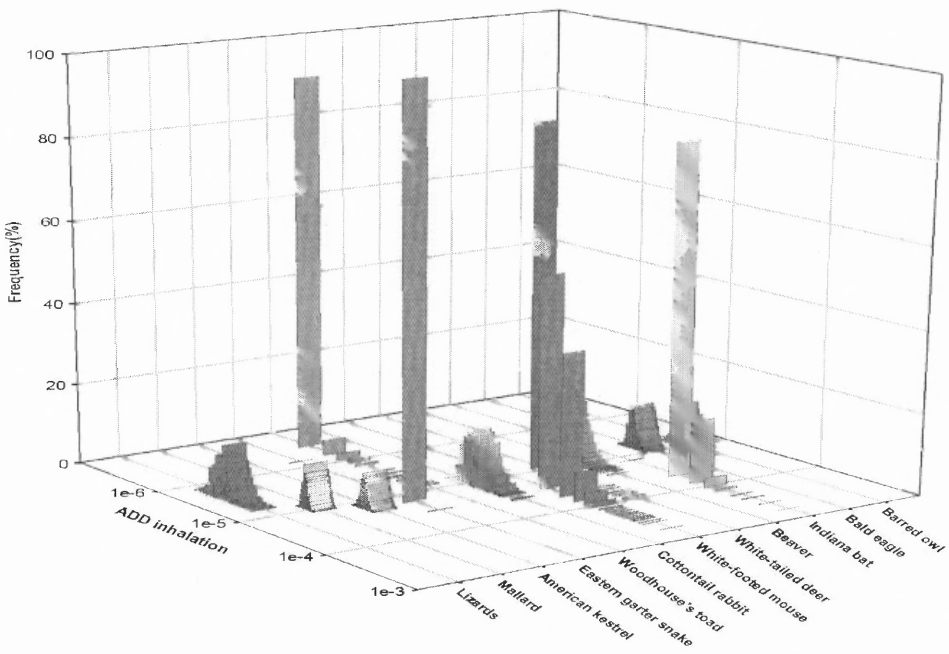


Figure F-9 ADD Inhalation Distribution (Mo) for Terrestrial Animals at APG.

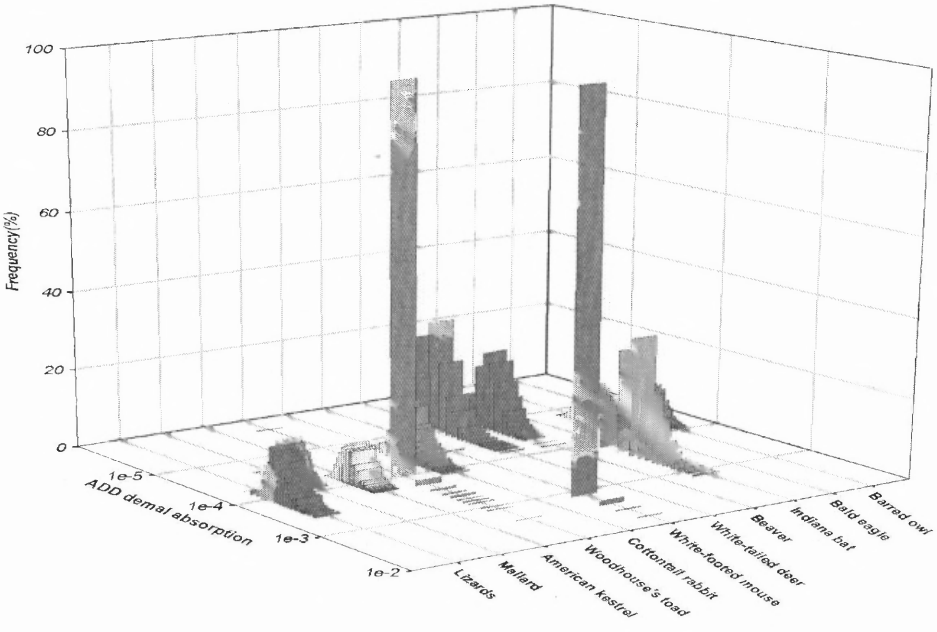


Figure F-10 ADD Dermal Absorption Distribution (Mo) for Terrestrial Animals at APG.

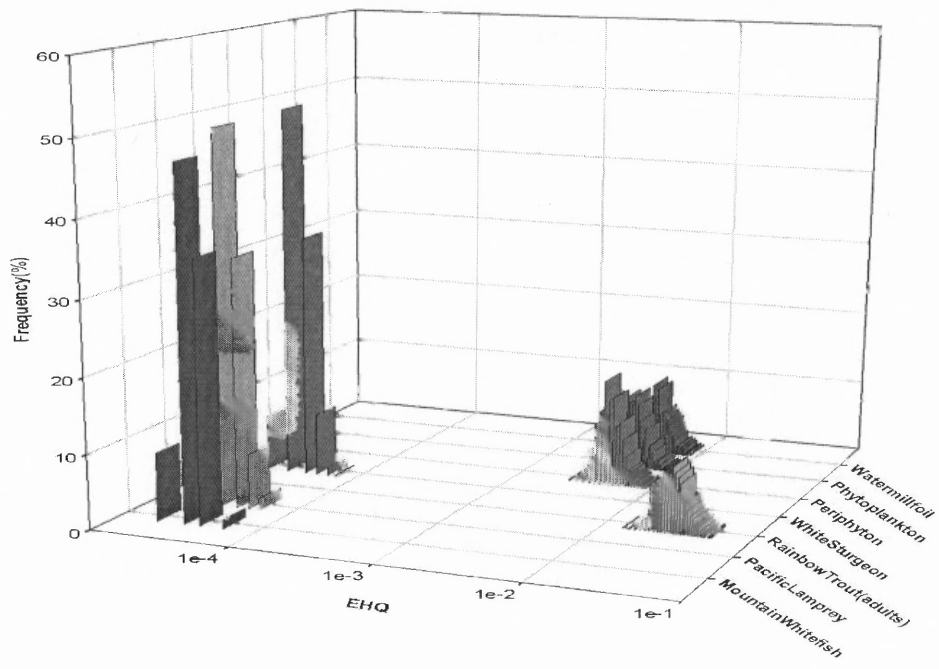


Figure F-11 EHQ Distribution (Mo) for Aquatic Species at APG.

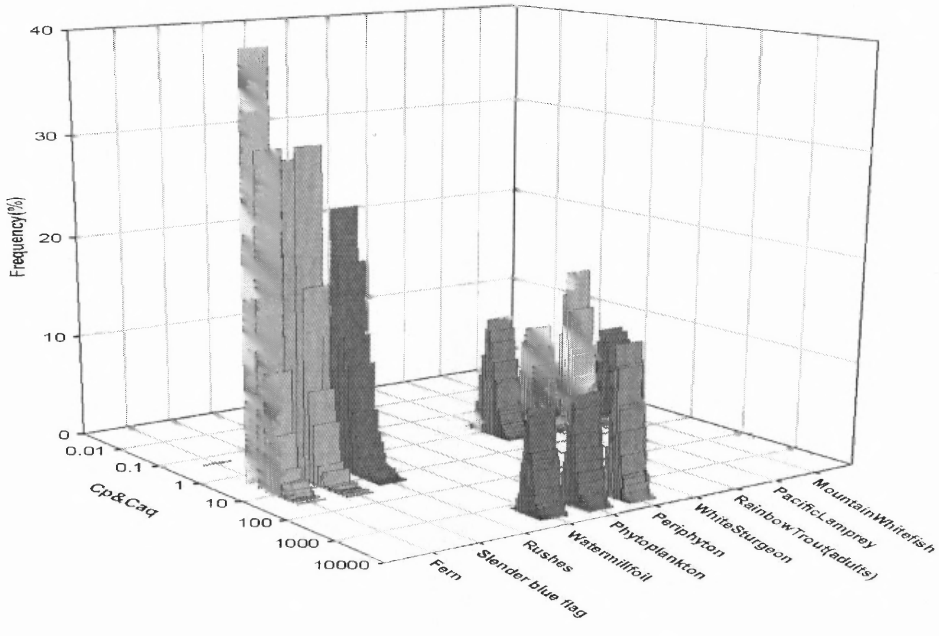


Figure F-12 Cp and Caq Distribution (Mo) for Terrestrial Plants and Aquatic Species at APG.

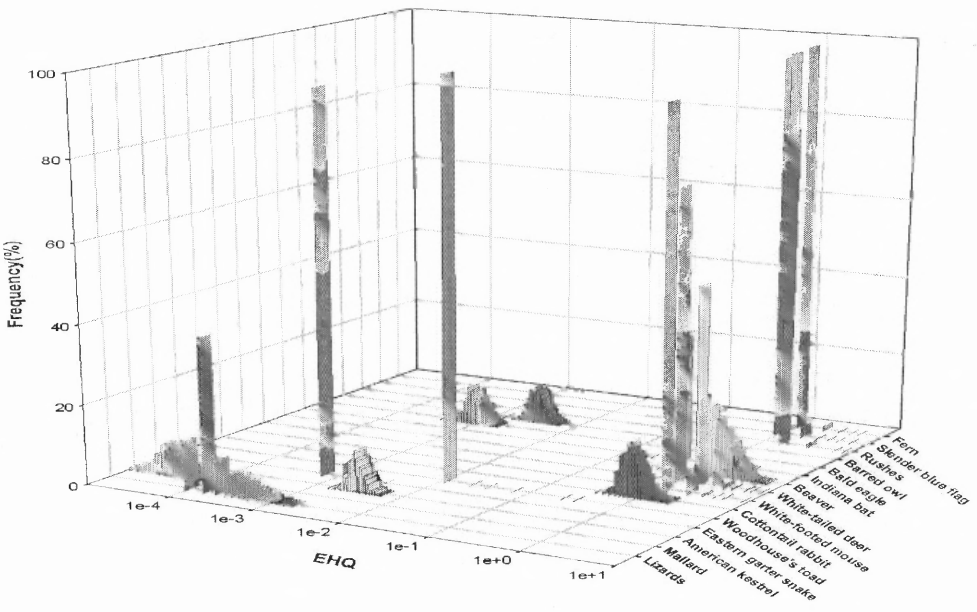


Figure F-13 EHQ Distribution (Ta) for Terrestrial Animal and Plant Receptors at APG.

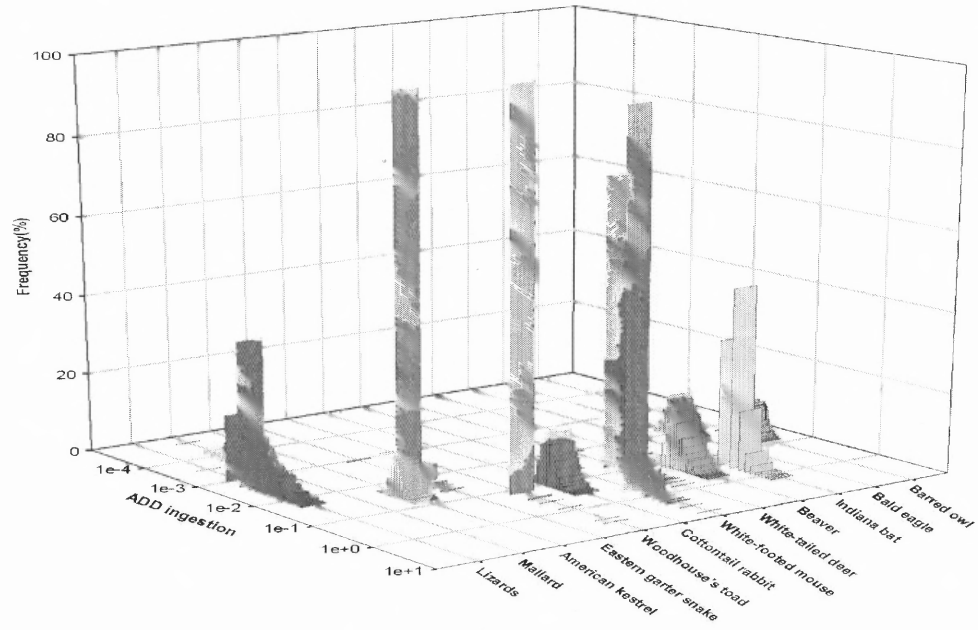


Figure F-14 ADD Ingestion Distribution (Ta) for Terrestrial Animals at APG.

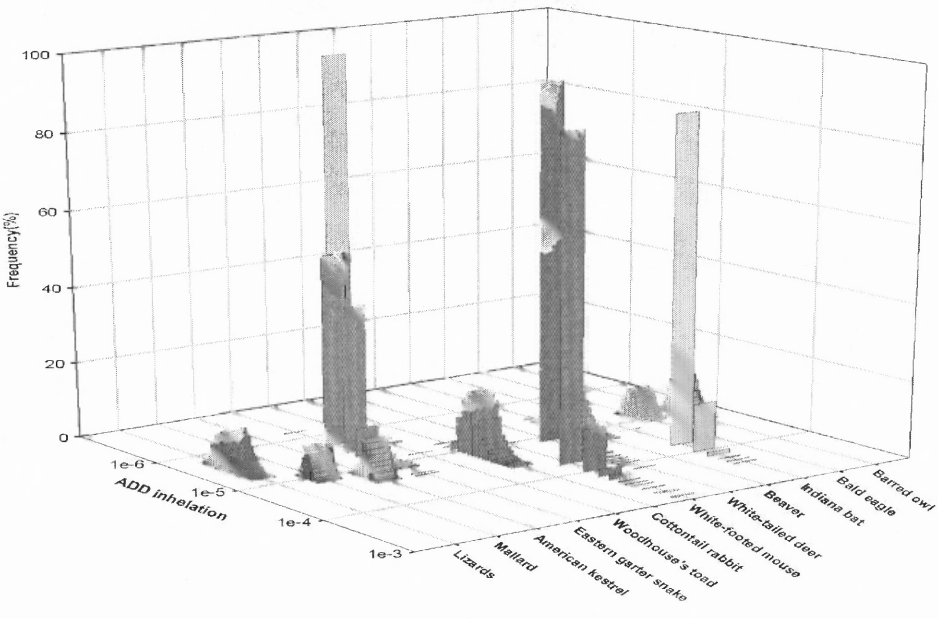


Figure F-15 ADD Inhalation Distribution (Ta) for Terrestrial Animals at APG.

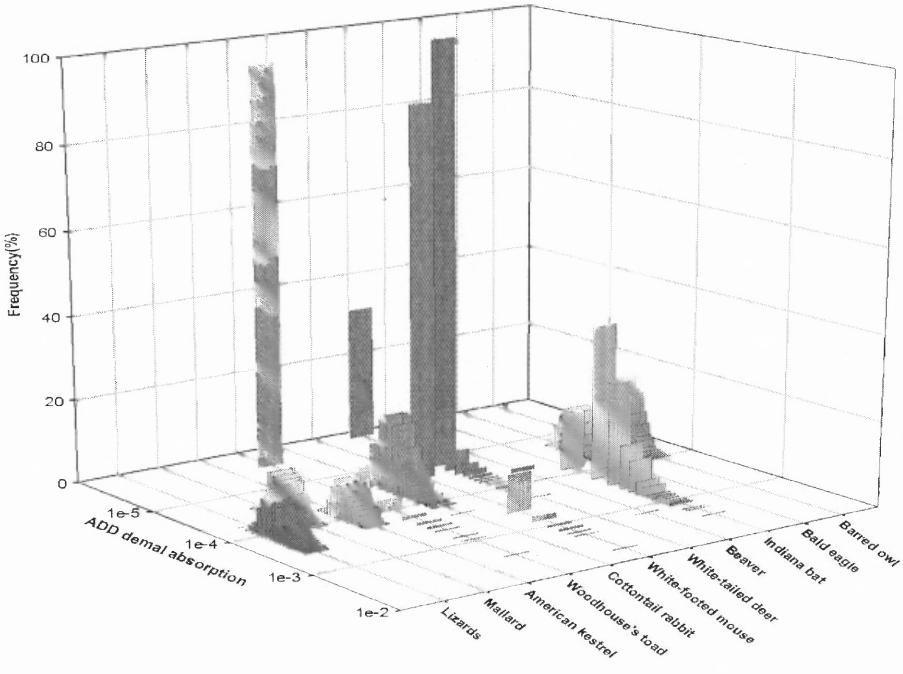


Figure F-16 ADD Dermal Absorption Distribution (Cr) for Terrestrial Animals at APG.

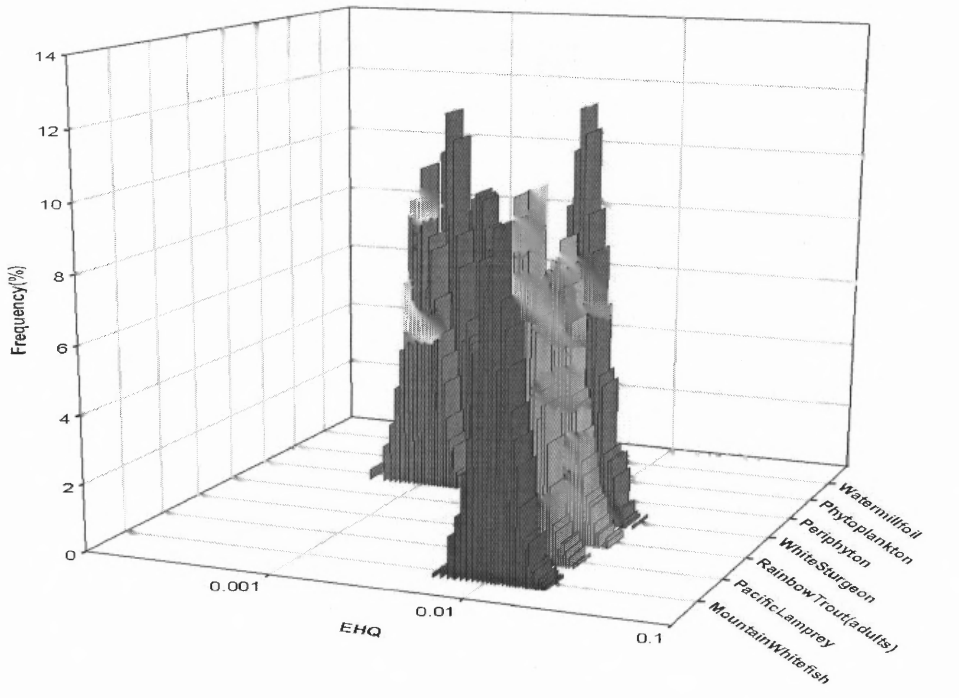


Figure F-17 EHQ Distribution (Ta) for Aquatic Species at APG.

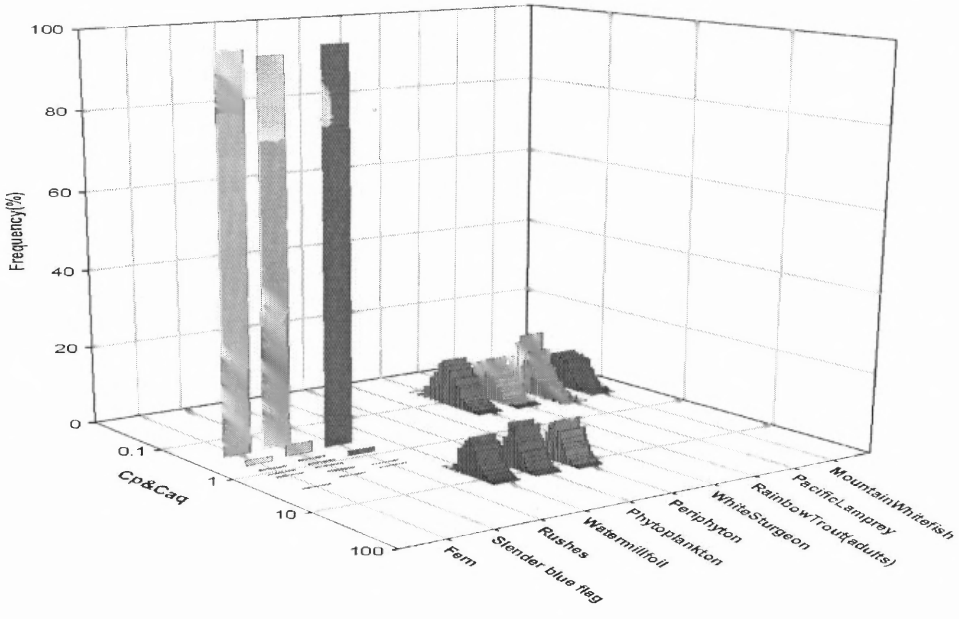


Figure F-18 Cp and Caq Distribution (Mo) for Terrestrial Plants and Aquatic Species at APG.

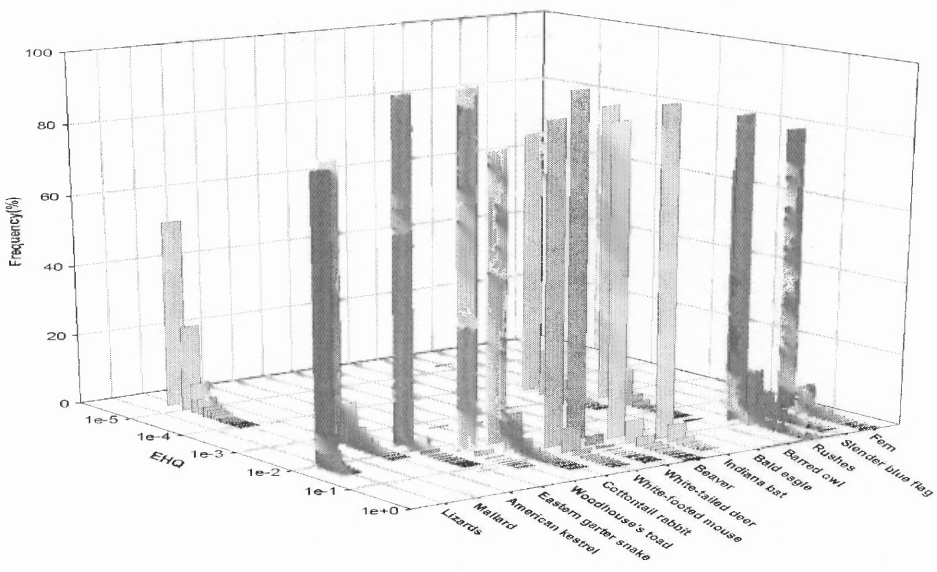


Figure F-19 EHQ Distribution (DU) for Terrestrial Animal and Plant Receptors at APG.

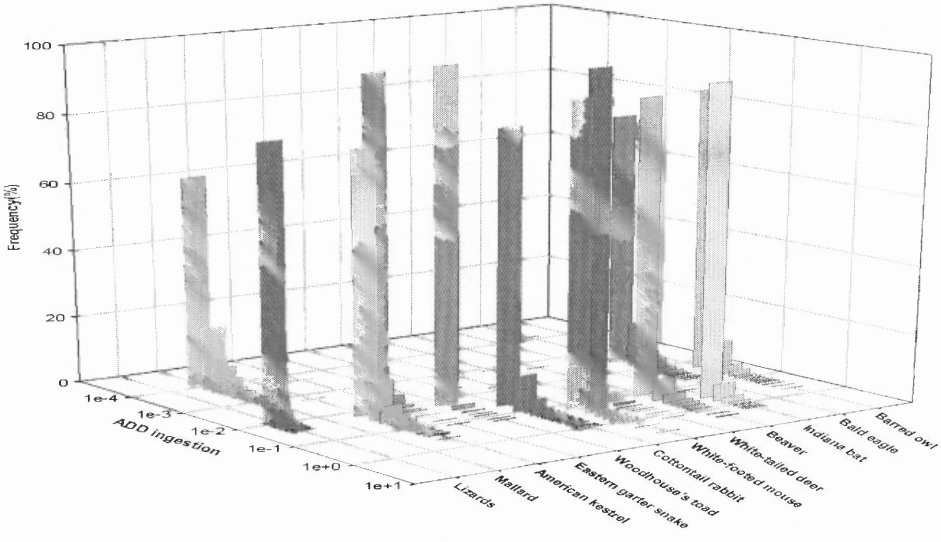


Figure F- 20 ADD Ingestion Distribution (DU) for Terrestrial Animals at APG.

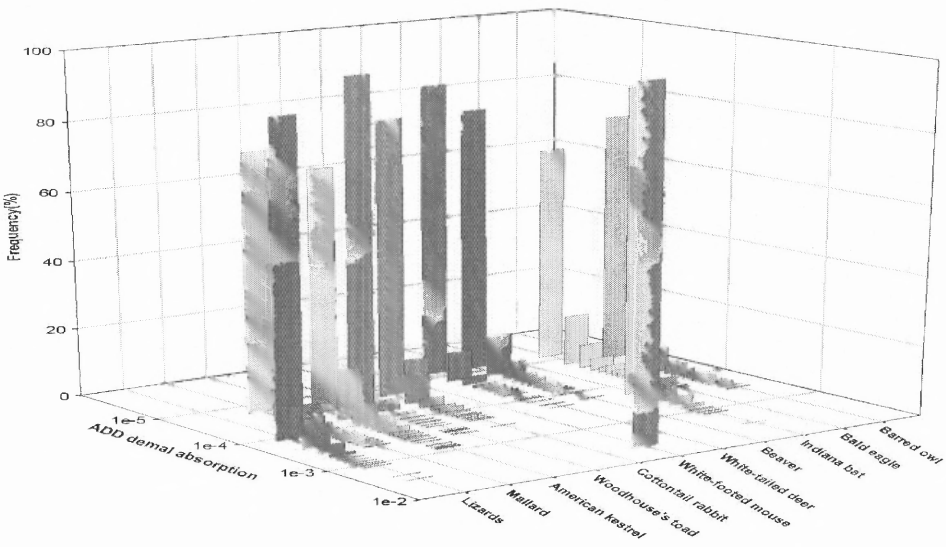


Figure F-21 ADD Dermal Absorption Distribution (DU) for Terrestrial Animals at APG.

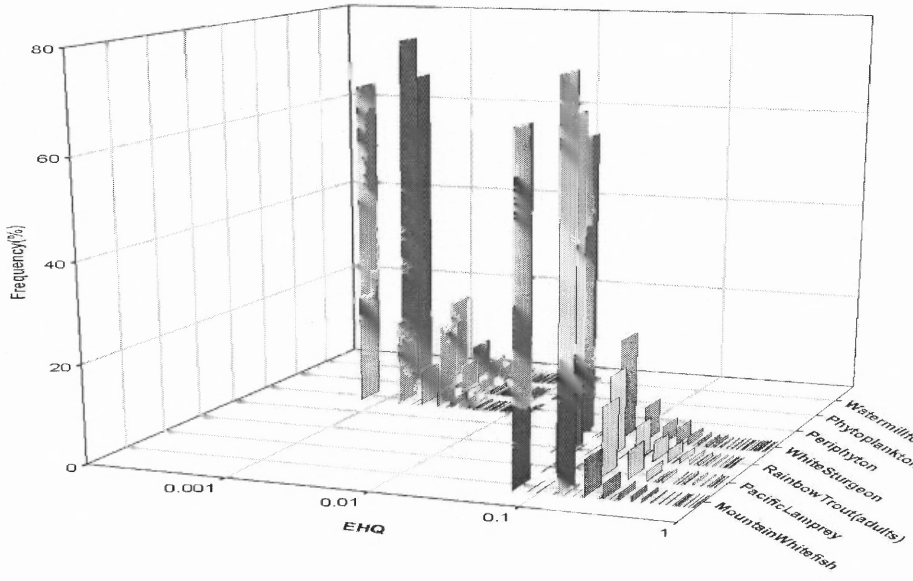


Figure F-22 EHQ Distribution (DU) for Aquatic Species at APG.

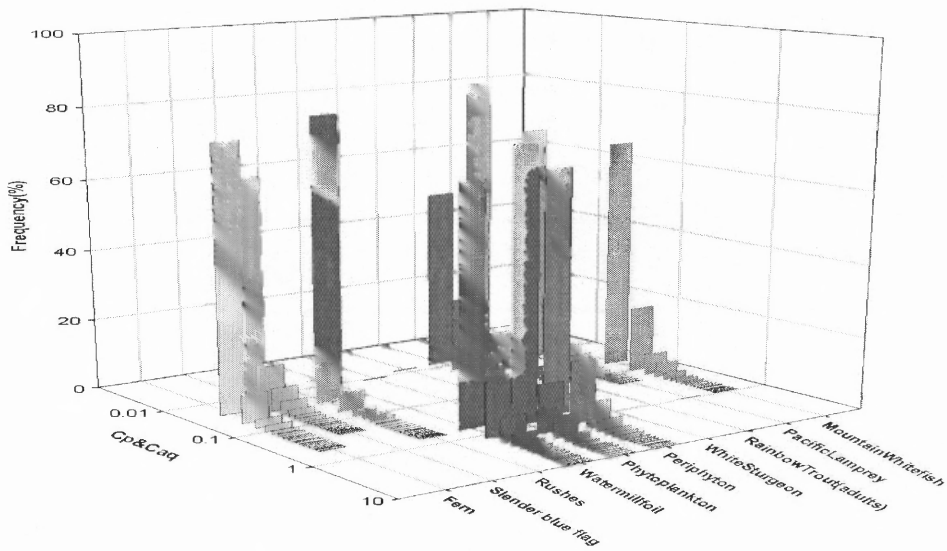


Figure F- 23 Cp and Caq Distribution (DU) for Terrestrial Plants and Aquatic Species at APG.

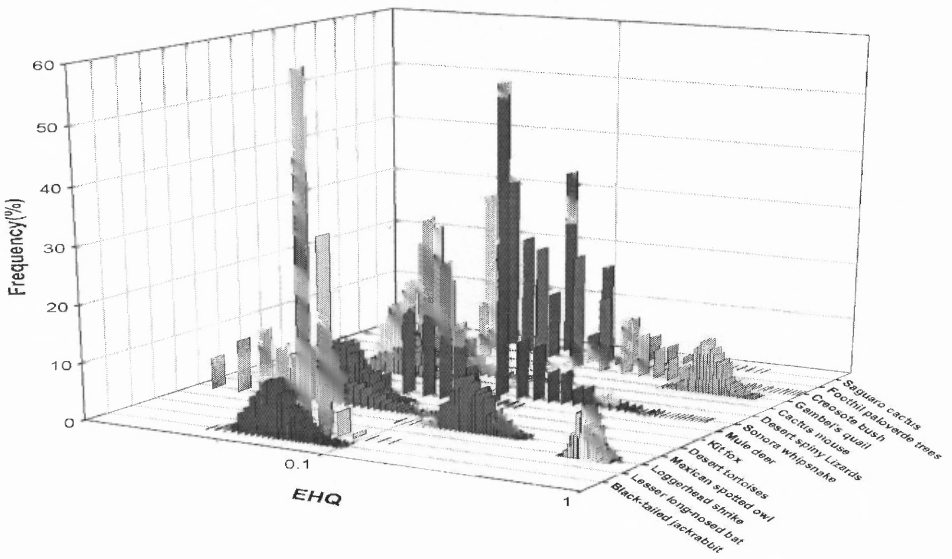


Figure F-24 EHQ Distribution (Cr) for Animal and Plant Receptors at YPG.

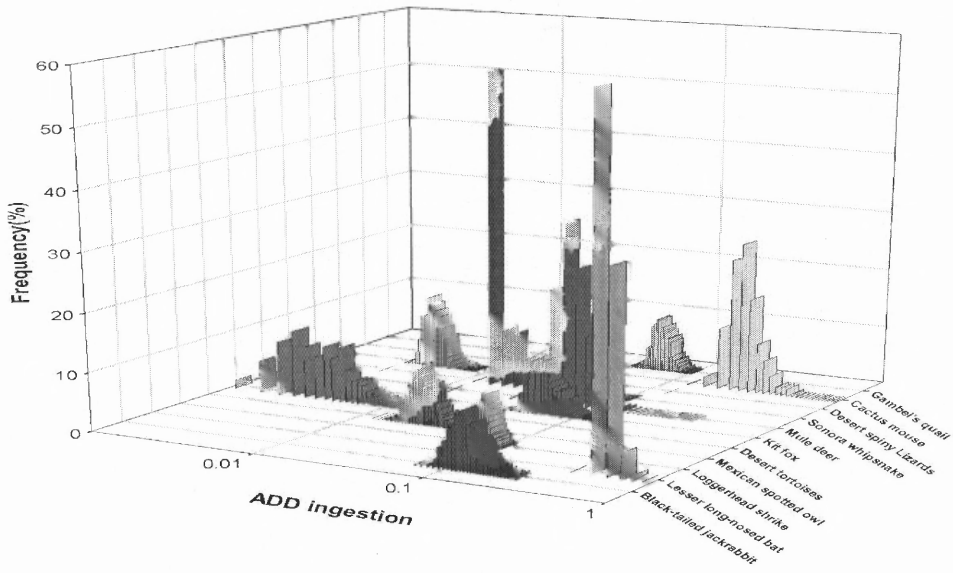


Figure F-25 ADD Ingestion Distribution (Cr) for Terrestrial Animals at YPG.

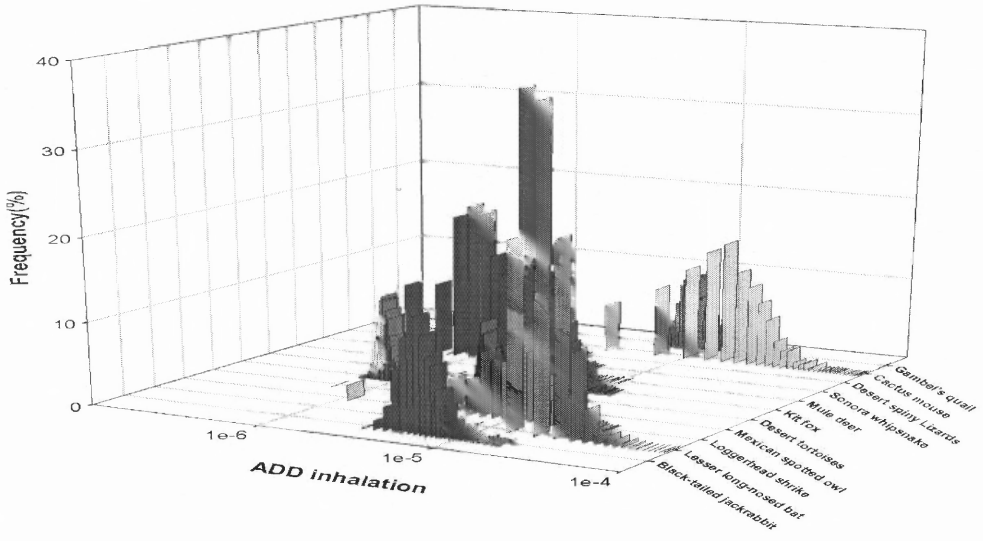


Figure F-26 ADD inhalation Distribution (Cr) for Terrestrial Animals at YPG.

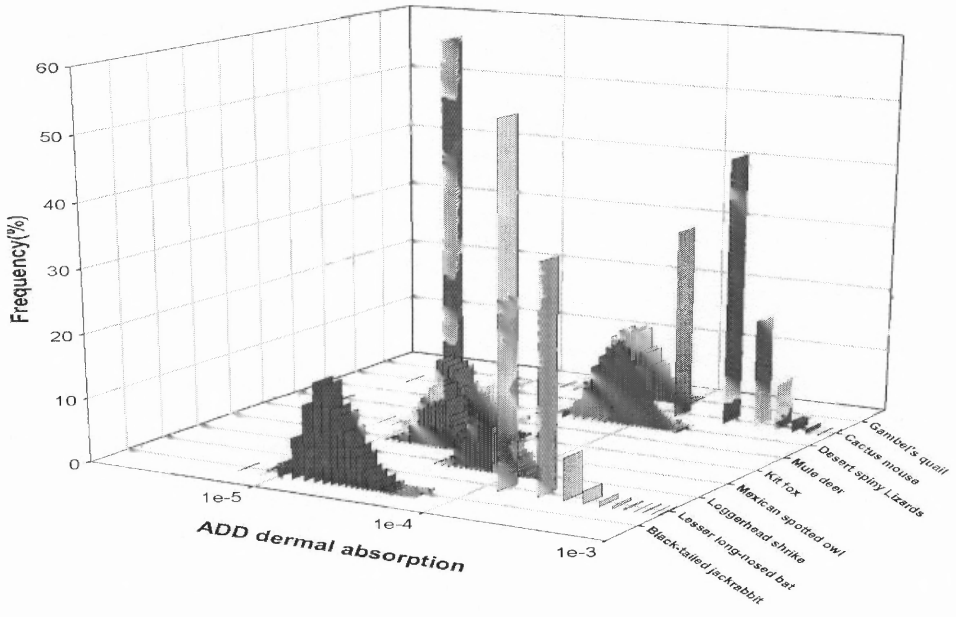


Figure F-27 ADD Dermal Absorption Distribution (Cr) for Terrestrial Animals at YPG.

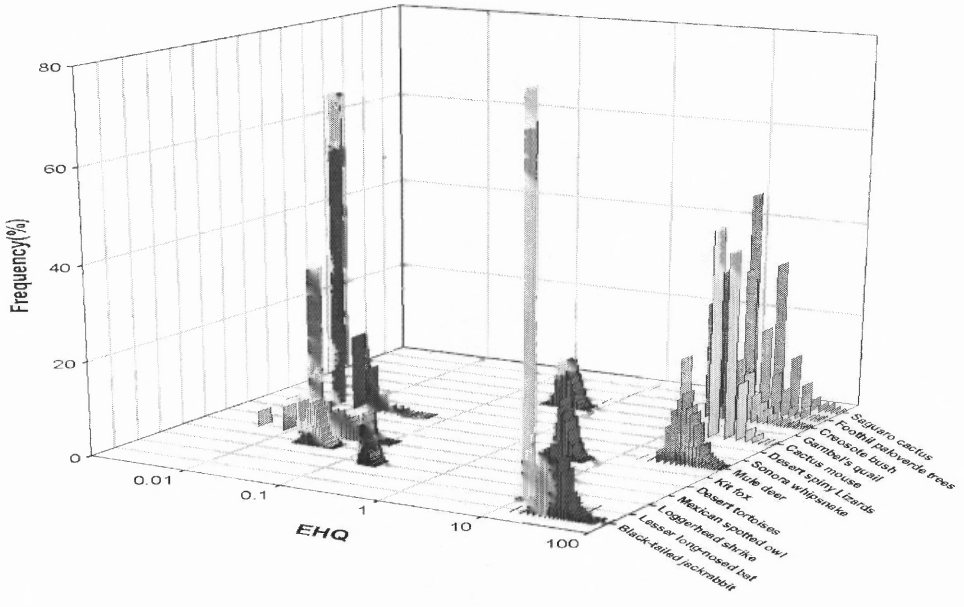
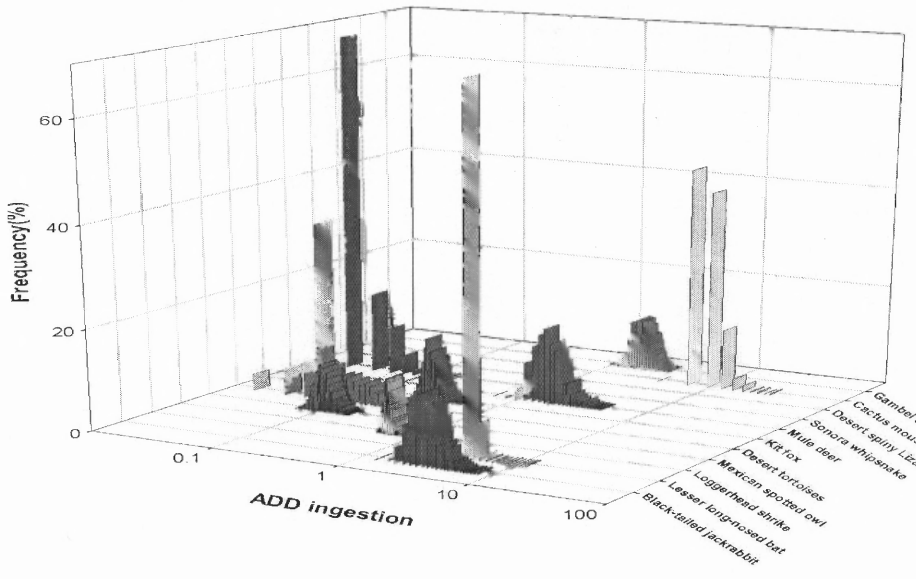


Figure F-28 EHQ Distribution (Mo) for Animal and Plant Receptors at YPG.



FigureE-29 ADD Ingestion Distribution (Mo) for Terrestrial Animals at YPG.

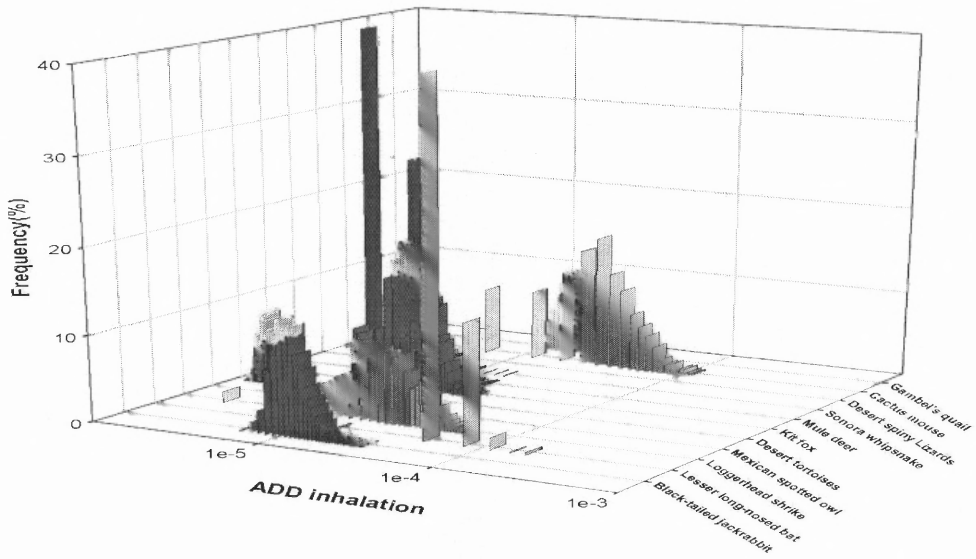


Figure F-30 ADD inhalation Distribution (Mo) for Terrestrial Animals at YPG.

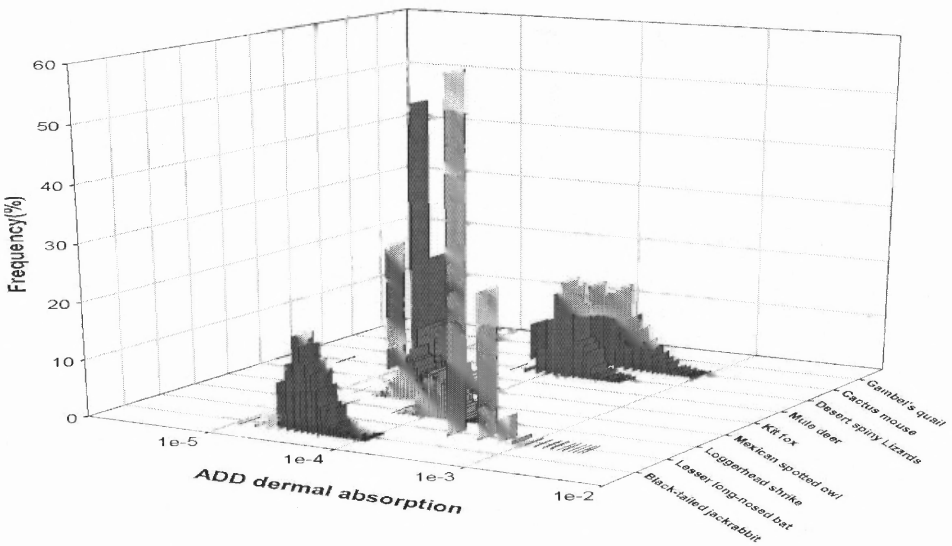


Figure F-31 ADD Dermal Absorption Distribution (Mo) for Terrestrial Animals at YPG.

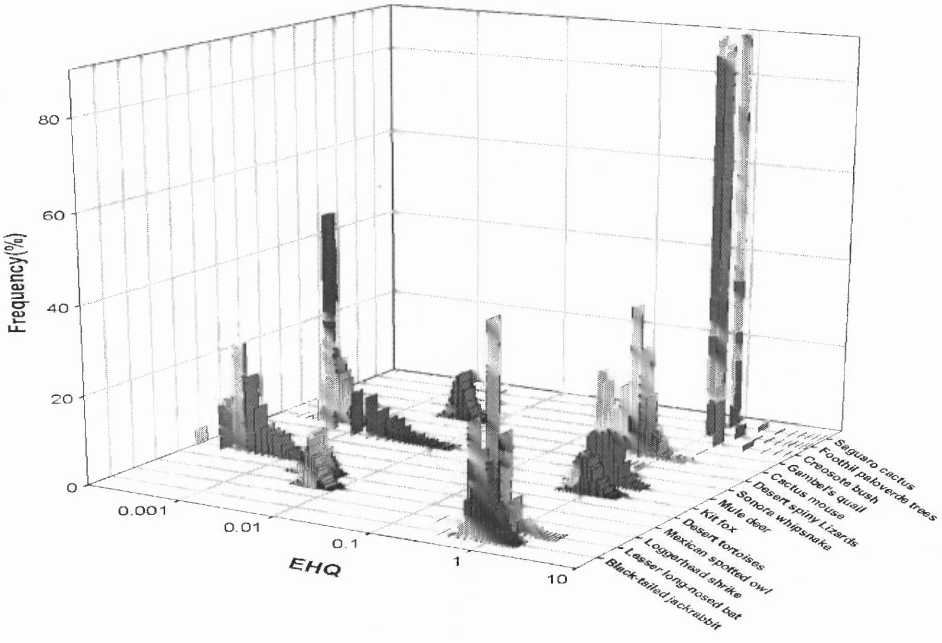


Figure F-32 EHQ Distribution (Ta) for Animal and Plant Receptors at YPG.

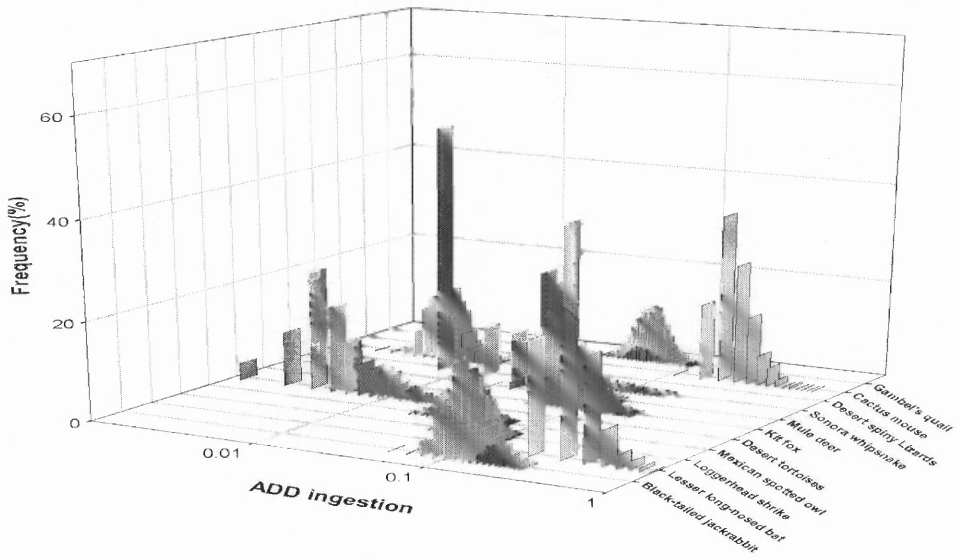


Figure F-33 ADD Ingestion Distribution (Ta) for Terrestrial Animals at YPG.

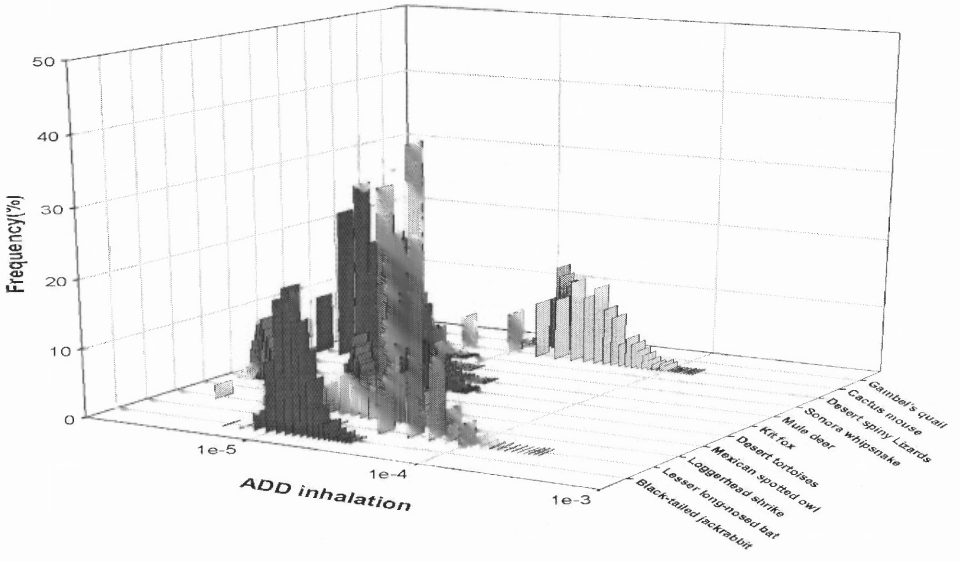


Figure F-34 ADD Inhalation Distribution (Ta) for Terrestrial Animals at YPG.

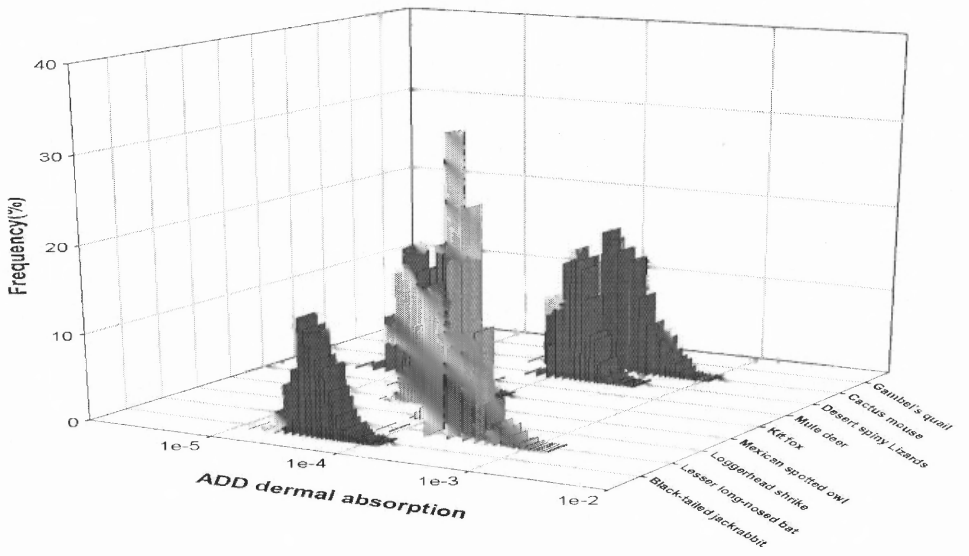


Figure F-35 ADD Dermal Absorption Distribution (Ta) for Terrestrial Animals at YPG.

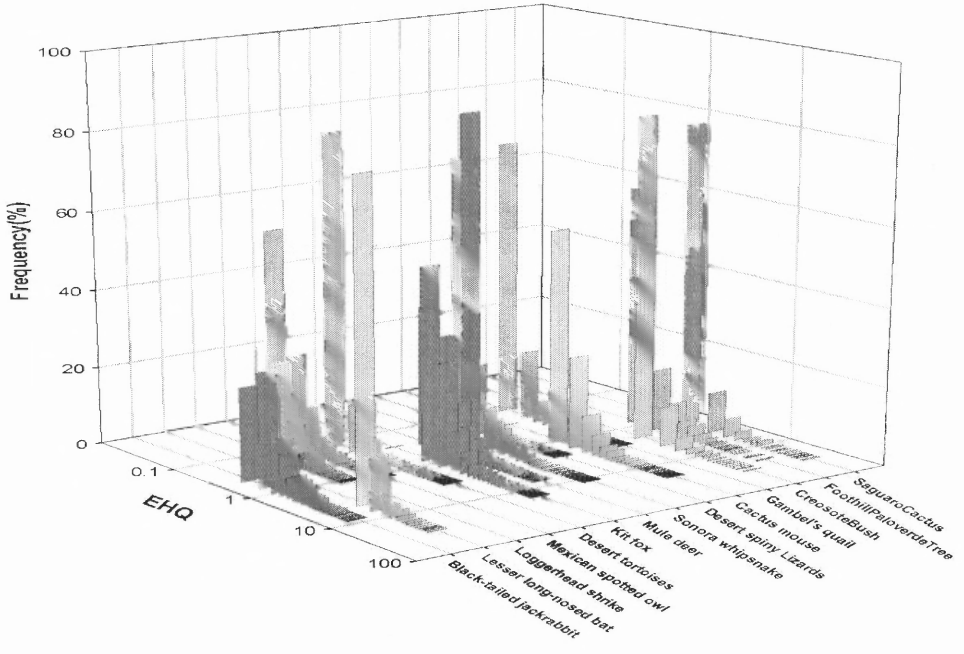


Figure F-36 EHQ Distribution (DU) for Animal and Plant Receptors at YPG.

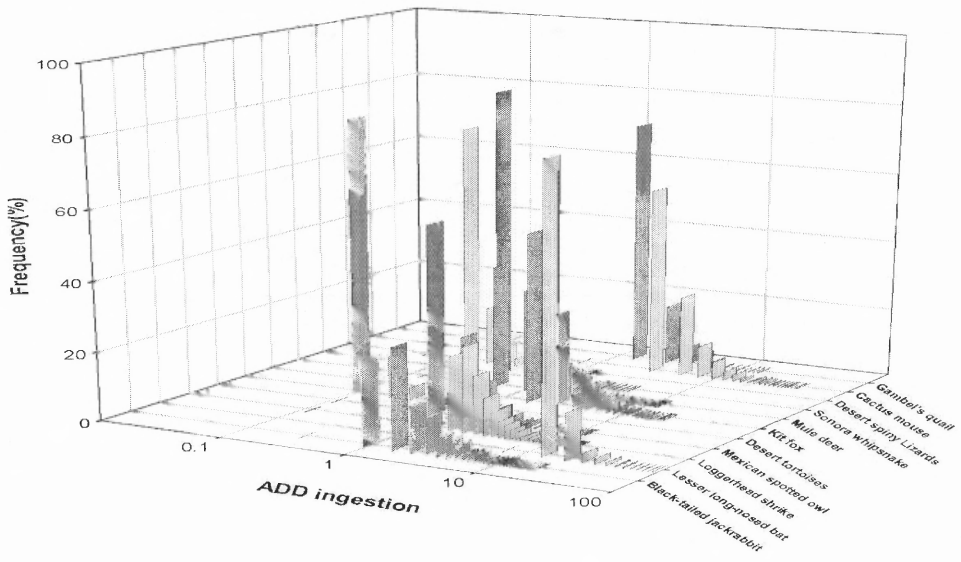


Figure F-37 ADD Ingestion Distribution (DU) for Terrestrial Animals at YPG.

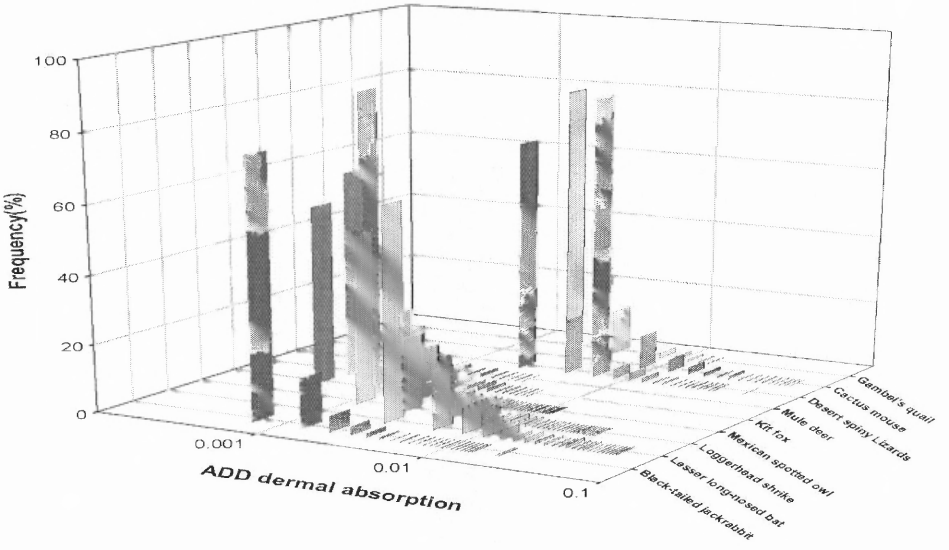
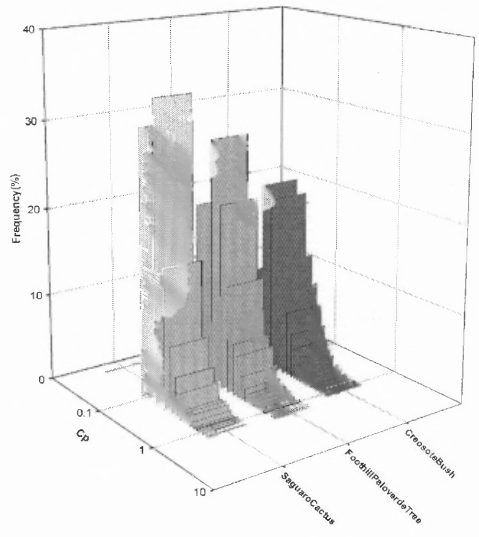
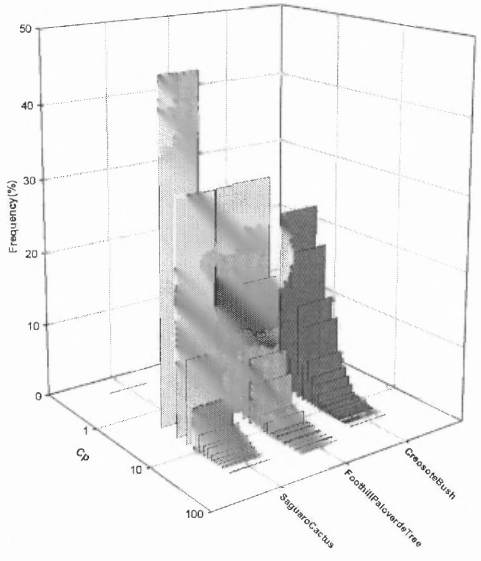


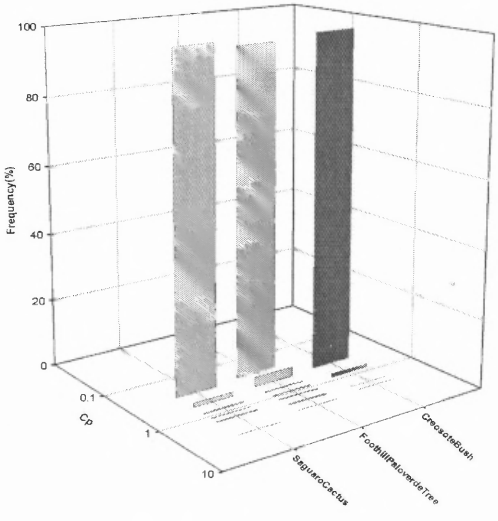
Figure F-38 ADD Dermal Absorption Distribution (DU) for Terrestrial Animals at YPG.



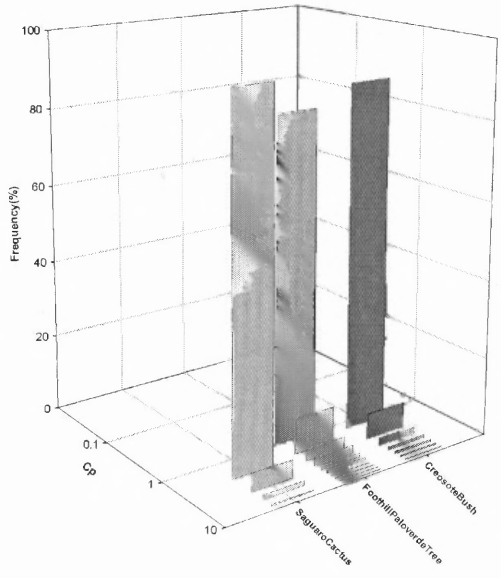
Chromium



Molybdenum



Tantalum



Uranium

Figure F-39 Cp Distributions for Terrestrial Plants at YPG.

APPENDIX G

STATISTICAL DATA

The statistical data include a mean, a standard error, a median, a standard deviation, a sample variance, a kurtosis, a skewness, a range, a minimum, a maximum, a sum, and a confidence level for each receptor in both YPG and APG sites.

Table G-1 EHQ of Cr(VI)for Terrestrial animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	3.69E-02	2.99E-04	1.91E-02	2.21E-02	9.43E-02	5.70E-02
Standard Error	4.88E-04	3.00E-06	1.39E-04	3.74E-04	5.50E-03	5.12E-04
Median	3.30E-02	2.94E-04	1.84E-02	1.96E-02	7.32E-02	5.46E-02
Standard Deviation	1.54E-02	9.48E-05	4.39E-03	1.18E-02	1.74E-01	1.62E-02
Sample Variance	2.38E-04	8.99E-09	1.93E-05	1.40E-04	3.02E-02	2.62E-04
Kurtosis	2.85E+00	-1.23E-01	1.07E+00	5.86E+01	3.06E+02	5.79E+01
Skewness	1.53E+00	1.65E-01	8.60E-01	6.28E+00	1.63E+01	4.45E+00
Range	9.75E-02	6.15E-04	2.76E-02	1.69E-01	3.87E+00	2.79E-01
Minimum	1.94E-02	4.09E-05	9.06E-03	1.01E-02	6.38E-02	2.76E-02
Maximum	1.17E-01	6.56E-04	3.67E-02	1.79E-01	3.93E+00	3.07E-01
Sum	3.69E+01	2.99E-01	1.91E+01	2.21E+01	9.43E+01	5.70E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	9.57E-04	5.88E-06	2.73E-04	7.33E-04	1.08E-02	1.00E-03

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	5.09E-02	7.72E-02	8.68E-02	4.98E-02	1.21E-01	1.98E-02
Standard Error	2.35E-03	2.30E-03	9.33E-04	2.96E-04	4.09E-04	1.52E-04
Median	3.80E-02	6.12E-02	8.07E-02	4.79E-02	1.20E-01	1.92E-02
Standard Deviation	7.42E-02	7.28E-02	2.95E-02	9.36E-03	1.29E-02	4.81E-03
Sample Variance	5.51E-03	5.29E-03	8.70E-04	8.76E-05	1.68E-04	2.31E-05
Kurtosis	1.66E+02	1.04E+02	1.05E+01	3.24E+01	2.67E-01	1.17E+00
Skewness	1.17E+01	8.18E+00	2.03E+00	4.35E+00	4.71E-01	7.63E-01
Range	1.27E+00	1.29E+00	3.37E-01	1.11E-01	8.06E-02	3.56E-02
Minimum	9.75E-03	1.78E-02	3.45E-02	3.82E-02	8.91E-02	8.78E-03
Maximum	1.28E+00	1.31E+00	3.72E-01	1.49E-01	1.70E-01	4.44E-02
Sum	5.09E+01	7.72E+01	8.68E+01	4.98E+01	1.21E+02	1.98E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.61E-03	4.51E-03	1.83E-03	5.81E-04	8.03E-04	2.98E-04

Table G-2 ADD Ingestion of Cr (VI) for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	4.90E-03	2.92E-04	1.91E-02	2.94E-03	1.25E-02	1.37E-01
Standard Error	6.49E-05	3.00E-06	1.39E-04	4.97E-05	7.31E-04	1.23E-03
Median	4.39E-03	2.87E-04	1.84E-02	2.60E-03	9.74E-03	1.32E-01
Standard Deviation	2.05E-03	9.49E-05	4.39E-03	1.57E-03	2.31E-02	3.90E-02
Sample Variance	4.21E-06	9.00E-09	1.93E-05	2.47E-06	5.35E-04	1.52E-03
Kurtosis	2.85E+00	-1.27E-01	1.07E+00	5.86E+01	3.06E+02	5.79E+01
Skewness	1.53E+00	1.67E-01	8.60E-01	6.28E+00	1.63E+01	4.45E+00
Range	1.30E-02	6.17E-04	2.76E-02	2.25E-02	5.15E-01	6.73E-01
Minimum	2.57E-03	3.24E-05	9.04E-03	1.35E-03	8.48E-03	6.65E-02
Maximum	1.55E-02	6.49E-04	3.67E-02	2.38E-02	5.23E-01	7.40E-01
Sum	4.90E+00	2.92E-01	1.91E+01	2.94E+00	1.25E+01	1.37E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.27E-04	5.89E-06	2.73E-04	9.75E-05	1.44E-03	2.42E-03

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	3.33E-01	7.11E-02	1.30E-01	4.26E-01	1.61E-02	1.98E-02
Standard Error	1.54E-02	2.12E-03	1.40E-03	2.54E-03	5.44E-05	1.52E-04
Median	2.49E-01	5.63E-02	1.21E-01	4.10E-01	1.59E-02	1.92E-02
Standard Deviation	4.86E-01	6.69E-02	4.42E-02	8.02E-02	1.72E-03	4.81E-03
Sample Variance	2.36E-01	4.48E-03	1.96E-03	6.43E-03	2.96E-06	2.31E-05
Kurtosis	1.66E+02	1.04E+02	1.05E+01	3.24E+01	2.67E-01	1.17E+00
Skewness	1.17E+01	8.18E+00	2.03E+00	4.35E+00	4.71E-01	7.63E-01
Range	8.32E+00	1.19E+00	5.06E-01	9.49E-01	1.07E-02	3.56E-02
Minimum	6.37E-02	1.64E-02	5.17E-02	3.27E-01	1.19E-02	8.77E-03
Maximum	8.38E+00	1.20E+00	5.58E-01	1.28E+00	2.26E-02	4.44E-02
Sum	3.33E+02	7.11E+01	1.30E+02	4.26E+02	1.61E+01	1.98E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.02E-02	4.15E-03	2.75E-03	4.98E-03	1.07E-04	2.98E-04

Table G-3 ADD Dermal Absorption of Cr (VI) for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	7.90E-05	2.48E-05	5.16E-05	0.00E+00	1.78E-05	2.40E-05
Standard Error	7.69E-07	1.79E-07	3.84E-07	0.00E+00	3.03E-06	2.87E-07
Median	7.52E-05	2.42E-05	5.05E-05	0.00E+00	6.26E-06	2.24E-05
Standard Deviation	2.43E-05	5.67E-06	1.21E-05	0.00E+00	9.58E-05	9.06E-06
Sample Variance	5.92E-10	3.22E-11	1.47E-10	0.00E+00	9.17E-09	8.21E-11
Kurtosis	2.92E+00	1.20E+00	2.34E-01	#DIV/0!	5.82E+02	9.35E+00
Skewness	1.17E+00	7.20E-01	5.50E-01	#DIV/0!	2.21E+01	1.98E+00
Range	1.97E-04	4.30E-05	7.86E-05	0.00E+00	2.65E-03	9.48E-05
Minimum	2.66E-05	1.14E-05	2.26E-05	0.00E+00	1.16E-06	6.43E-06
Maximum	2.23E-04	5.44E-05	1.01E-04	0.00E+00	2.65E-03	1.01E-04
Sum	7.90E-02	2.48E-02	5.16E-02	0.00E+00	1.78E-02	2.40E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.51E-06	3.52E-07	7.53E-07	0.00E+00	5.94E-06	5.62E-07

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	1.50E-04	6.47E-06	9.26E-06	1.43E-04	1.67E-05	2.37E-05
Standard Error	1.88E-05	1.69E-07	1.31E-07	2.83E-06	1.37E-07	2.00E-07
Median	9.54E-05	5.23E-06	8.52E-06	1.23E-04	1.59E-05	2.27E-05
Standard Deviation	5.93E-04	5.33E-06	4.13E-06	8.96E-05	4.35E-06	6.34E-06
Sample Variance	3.52E-07	2.84E-11	1.71E-11	8.02E-09	1.89E-11	4.02E-11
Kurtosis	6.18E+02	3.86E+01	9.94E+00	2.86E+01	1.64E+00	2.74E-01
Skewness	2.38E+01	4.98E+00	2.29E+00	4.25E+00	1.03E+00	6.46E-01
Range	1.65E-02	6.74E-05	3.92E-05	1.04E-03	3.11E-05	4.02E-05
Minimum	1.93E-05	8.16E-07	2.37E-06	3.42E-05	7.51E-06	9.55E-06
Maximum	1.65E-02	6.82E-05	4.15E-05	1.08E-03	3.87E-05	4.98E-05
Sum	1.50E-01	6.47E-03	9.26E-03	1.43E-01	1.67E-02	2.37E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.68E-05	3.31E-07	2.56E-07	5.56E-06	2.70E-07	3.93E-07

Table G-4 ADD Inhalation of Cr (VI) for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	1.51E-06	5.09E-06	8.48E-06	1.18E-06	7.64E-08	7.00E-06
Standard Error	1.18E-08	1.26E-08	2.64E-08	2.71E-08	1.04E-08	6.42E-08
Median	1.47E-06	5.08E-06	8.43E-06	9.74E-07	3.23E-08	6.54E-06
Standard Deviation	3.73E-07	3.97E-07	8.36E-07	8.55E-07	3.28E-07	2.03E-06
Sample Variance	1.39E-13	1.58E-13	6.99E-13	7.32E-13	1.08E-13	4.12E-12
Kurtosis	1.83E+00	-9.80E-02	2.85E-02	6.23E+01	2.85E+02	4.23E+00
Skewness	9.62E-01	1.35E-01	2.82E-01	6.53E+00	1.55E+01	1.54E+00
Range	2.57E-06	2.45E-06	5.76E-06	1.23E-05	7.24E-06	1.67E-05
Minimum	7.08E-07	4.00E-06	6.02E-06	3.52E-07	3.58E-09	3.34E-06
Maximum	3.28E-06	6.45E-06	1.18E-05	1.27E-05	7.24E-06	2.01E-05
Sum	1.51E-03	5.09E-03	8.48E-03	1.18E-03	7.64E-05	7.00E-03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.32E-08	2.46E-08	5.19E-08	5.31E-08	2.04E-08	1.26E-07

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.23E-05	3.40E-06	4.08E-06	2.03E-05	3.91E-06	4.95E-06
Standard Error	2.22E-06	6.65E-08	4.44E-08	3.85E-07	1.45E-08	2.17E-08
Median	1.45E-05	2.89E-06	3.80E-06	1.79E-05	3.87E-06	4.89E-06
Standard Deviation	7.01E-05	2.10E-06	1.40E-06	1.22E-05	4.58E-07	6.85E-07
Sample Variance	4.92E-09	4.43E-12	1.97E-12	1.48E-10	2.10E-13	4.69E-13
Kurtosis	5.55E+02	5.09E+01	1.61E+01	1.09E+02	2.75E-01	8.56E-01
Skewness	2.15E+01	5.20E+00	2.73E+00	7.88E+00	4.96E-01	6.46E-01
Range	1.92E-03	2.95E-05	1.54E-05	2.27E-04	2.81E-06	5.10E-06
Minimum	4.63E-06	1.03E-06	1.96E-06	8.06E-06	2.77E-06	2.96E-06
Maximum	1.93E-03	3.06E-05	1.74E-05	2.35E-04	5.59E-06	8.05E-06
Sum	2.23E-02	3.40E-03	4.08E-03	2.03E-02	3.91E-03	4.95E-03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.35E-06	1.31E-07	8.71E-08	7.56E-07	2.84E-08	4.25E-08

Table G-4 EHQ of Cr for Terrestrial Plants and Aquatic Species at APG

Statistical data	*Terrestrial Plants*			*Aquatic Plants*		
	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	2.46E-01	2.28E-01	9.51E-01	2.04E-03	2.07E-03	2.04E-04
Standard Error	6.53E-03	6.54E-03	2.80E-02	1.48E-05	1.52E-05	1.45E-06
Median	1.86E-01	1.78E-01	6.82E-01	1.98E-03	2.01E-03	2.00E-04
Standard Deviation	2.06E-01	2.07E-01	8.86E-01	4.69E-04	4.80E-04	4.58E-05
Sample Variance	4.26E-02	4.28E-02	7.84E-01	2.20E-07	2.31E-07	2.10E-09
Kurtosis	1.10E+01	2.62E+01	3.47E+01	4.58E-01	1.22E+00	2.09E+00
Skewness	2.68E+00	3.90E+00	4.14E+00	6.98E-01	7.99E-01	8.68E-01
Range	1.80E+00	2.43E+00	1.24E+01	2.88E-03	3.47E-03	3.70E-04
Minimum	1.70E-02	1.20E-02	9.00E-02	9.60E-04	9.20E-04	9.00E-05
Maximum	1.82E+00	2.44E+00	1.25E+01	3.84E-03	4.39E-03	4.60E-04
Sum	2.46E+02	2.28E+02	9.51E+02	2.04E+00	2.07E+00	2.04E-01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	1.28E-02	1.28E-02	5.50E-02	2.91E-05	2.98E-05	2.84E-06

Statistical data	*Aquatic Animals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	2.05E-03	2.02E-03	2.07E-04	7.15E-05
Standard Error	1.43E-05	1.48E-05	1.49E-06	5.24E-07
Median	2.00E-03	1.97E-03	2.00E-04	7.00E-05
Standard Deviation	4.54E-04	4.68E-04	4.72E-05	1.66E-05
Sample Variance	2.06E-07	2.19E-07	2.22E-09	2.75E-10
Kurtosis	1.18E+00	1.32E+00	3.31E+00	1.01E+00
Skewness	8.17E-01	7.46E-01	1.05E+00	7.20E-01
Range	3.10E-03	3.48E-03	4.30E-04	1.10E-04
Minimum	1.08E-03	9.20E-04	1.10E-04	4.00E-05
Maximum	4.18E-03	4.40E-03	5.40E-04	1.50E-04
Sum	2.05E+00	2.02E+00	2.07E-01	7.15E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	2.82E-05	2.90E-05	2.93E-06	1.03E-06

Table G-5 Cp of Cr for Terrestrial Plants and Aquatic Species at APG

	Terrestrial Plants			*Aquatic Plants*		
Statistical data	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	1.67E-01	1.68E-01	1.71E-01	7.51E+01	1.09E+02	7.51E+01
Standard Error	4.44E-03	4.84E-03	5.04E-03	5.45E-01	8.03E-01	5.32E-01
Median	1.26E-01	1.32E-01	1.23E-01	7.28E+01	1.06E+02	7.35E+01
Standard Deviation	1.40E-01	1.53E-01	1.59E-01	1.72E+01	2.54E+01	1.68E+01
Sample Variance	1.97E-02	2.34E-02	2.54E-02	2.98E+02	6.45E+02	2.83E+02
Kurtosis	1.10E+01	2.62E+01	3.47E+01	4.60E-01	1.22E+00	2.04E+00
Skewness	2.68E+00	3.90E+00	4.14E+00	6.97E-01	7.99E-01	8.69E-01
Range	1.23E+00	1.80E+00	2.24E+00	1.06E+02	1.83E+02	1.34E+02
Minimum	1.10E-02	9.00E-03	1.60E-02	3.55E+01	4.89E+01	3.39E+01
Maximum	1.24E+00	1.81E+00	2.25E+00	1.41E+02	2.32E+02	1.68E+02
Sum	1.67E+02	1.68E+02	1.71E+02	7.51E+04	1.09E+05	7.51E+04
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	8.71E-03	9.50E-03	9.89E-03	1.07E+00	1.58E+00	1.04E+00

Statistical data	*Aquatic Annimals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	4.72E+00	4.64E+00	4.76E+00	4.68E+00
Standard Error	3.30E-02	3.40E-02	3.42E-02	3.38E-02
Median	4.60E+00	4.52E+00	4.63E+00	4.57E+00
Standard Deviation	1.04E+00	1.08E+00	1.08E+00	1.07E+00
Sample Variance	1.09E+00	1.16E+00	1.17E+00	1.14E+00
Kurtosis	1.21E+00	1.32E+00	3.25E+00	1.21E+00
Skewness	8.24E-01	7.46E-01	1.05E+00	7.72E-01
Range	7.14E+00	8.00E+00	9.93E+00	7.54E+00
Minimum	2.49E+00	2.11E+00	2.44E+00	2.38E+00
Maximum	9.63E+00	1.01E+01	1.24E+01	9.92E+00
Sum	4.72E+03	4.64E+03	4.76E+03	4.68E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	6.48E-02	6.68E-02	6.72E-02	6.64E-02

Table G-6 EHQ of Mo for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	2.66E-02	1.85E-03	1.60E-02	4.34E-03	5.93E-03	3.51E+01
Standard Error	2.60E-05	2.38E-05	8.15E-05	2.57E-04	1.38E-03	3.61E-01
Median	2.62E-02	1.87E-03	1.57E-02	3.90E-03	3.73E-03	3.30E+01
Standard Deviation	8.21E-04	7.52E-04	2.58E-03	8.13E-03	4.36E-02	1.14E+01
Sample Variance	6.74E-07	5.66E-07	6.64E-06	6.61E-05	1.90E-03	1.31E+02
Kurtosis	4.69E+00	-5.72E-02	4.25E-01	9.80E+02	9.90E+02	8.33E+00
Skewness	2.02E+00	1.75E-01	5.46E-01	3.12E+01	3.14E+01	1.98E+00
Range	5.17E-03	4.27E-03	1.63E-02	2.57E-01	1.38E+00	1.06E+02
Minimum	2.59E-02	1.19E-04	1.00E-02	3.34E-03	3.03E-03	1.36E+01
Maximum	3.11E-02	4.39E-03	2.63E-02	2.60E-01	1.38E+00	1.20E+02
Sum	2.66E+01	1.85E+00	1.60E+01	4.34E+00	5.93E+00	3.51E+04
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	5.10E-05	4.67E-05	1.60E-04	5.05E-04	2.70E-03	7.09E-01

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	3.74E+01	5.48E+01	2.81E+01	5.89E+00	4.38E-03	1.36E-02
Standard Error	5.27E+00	4.46E+00	3.23E-01	1.04E-02	2.51E-05	8.35E-05
Median	2.42E+01	4.01E+01	2.61E+01	5.81E+00	4.28E-03	1.33E-02
Standard Deviation	1.67E+02	1.41E+02	1.02E+01	3.29E-01	7.92E-04	2.64E-03
Sample Variance	2.78E+04	1.99E+04	1.04E+02	1.08E-01	6.28E-07	6.97E-06
Kurtosis	8.97E+02	4.33E+02	6.10E+00	2.15E+01	1.54E+00	7.62E-01
Skewness	2.93E+01	1.95E+01	1.88E+00	2.93E+00	7.89E-01	6.62E-01
Range	5.16E+03	3.52E+03	8.18E+01	4.40E+00	6.59E-03	1.83E-02
Minimum	4.71E+00	2.42E+00	8.11E+00	5.36E+00	2.60E-03	7.39E-03
Maximum	5.16E+03	3.52E+03	8.99E+01	9.76E+00	9.19E-03	2.57E-02
Sum	3.74E+04	5.48E+04	2.81E+04	5.89E+03	4.38E+00	1.36E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.03E+01	8.75E+00	6.34E-01	2.04E-02	4.92E-05	1.64E-04

Table G-7 ADD Ingestion of Mo for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	9.30E-02	6.42E-03	5.57E-02	1.52E-02	2.07E-02	3.51E+00
Standard Error	9.08E-05	8.33E-05	2.85E-04	9.00E-04	4.82E-03	3.61E-02
Median	9.16E-02	6.50E-03	5.49E-02	1.37E-02	1.30E-02	3.30E+00
Standard Deviation	2.87E-03	2.63E-03	9.02E-03	2.85E-02	1.52E-01	1.14E+00
Sample Variance	8.25E-06	6.93E-06	8.13E-05	8.10E-04	2.32E-02	1.31E+00
Kurtosis	4.65E+00	-5.66E-02	4.26E-01	9.80E+02	9.90E+02	8.33E+00
Skewness	2.02E+00	1.74E-01	5.47E-01	3.12E+01	3.14E+01	1.98E+00
Range	1.79E-02	1.50E-02	5.69E-02	8.98E-01	4.81E+00	1.06E+01
Minimum	9.05E-02	3.57E-04	3.49E-02	1.17E-02	1.06E-02	1.36E+00
Maximum	1.08E-01	1.53E-02	9.19E-02	9.10E-01	4.83E+00	1.20E+01
Sum	9.30E+01	6.42E+00	5.57E+01	1.52E+01	2.07E+01	3.51E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.78E-04	1.63E-04	5.60E-04	1.77E-03	9.46E-03	7.09E-02

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	1.05E+01	2.19E+00	1.69E+00	2.18E+00	1.53E-02	4.74E-02
Standard Error	1.48E+00	1.78E-01	1.94E-02	3.85E-03	8.77E-05	2.92E-04
Median	6.77E+00	1.61E+00	1.56E+00	2.15E+00	1.49E-02	4.64E-02
Standard Deviation	4.67E+01	5.64E+00	6.13E-01	1.22E-01	2.77E-03	9.24E-03
Sample Variance	2.18E+03	3.18E+01	3.76E-01	1.48E-02	7.69E-06	8.54E-05
Kurtosis	8.97E+02	4.33E+02	6.10E+00	2.15E+01	1.53E+00	7.62E-01
Skewness	2.93E+01	1.95E+01	1.88E+00	2.93E+00	7.88E-01	6.63E-01
Range	1.44E+03	1.41E+02	4.91E+00	1.63E+00	2.30E-02	6.41E-02
Minimum	1.32E+00	9.69E-02	4.87E-01	1.98E+00	9.06E-03	2.58E-02
Maximum	1.45E+03	1.41E+02	5.39E+00	3.61E+00	3.21E-02	8.99E-02
Sum	1.05E+04	2.19E+03	1.69E+03	2.18E+03	1.53E+01	4.74E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.90E+00	3.50E-01	3.80E-02	7.55E-03	1.72E-04	5.73E-04

Table G-8 ADD Dermal Absorption of Mo for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	1.43E-04	4.53E-05	9.43E-05	0.00E+00	2.93E-05	4.49E-05
Standard Error	1.45E-06	3.38E-07	7.37E-07	0.00E+00	4.35E-06	5.35E-07
Median	1.35E-04	4.41E-05	9.12E-05	0.00E+00	1.10E-05	4.20E-05
Standard Deviation	4.60E-05	1.07E-05	2.33E-05	0.00E+00	1.38E-04	1.69E-05
Sample Variance	2.11E-09	1.14E-10	5.43E-10	0.00E+00	1.89E-08	2.86E-10
Kurtosis	3.56E+00	6.03E-01	1.09E+00	#DIV/0!	2.92E+02	3.78E+00
Skewness	1.35E+00	6.95E-01	9.08E-01	#DIV/0!	1.58E+01	1.44E+00
Range	3.61E-04	6.86E-05	1.52E-04	0.00E+00	2.90E-03	1.37E-04
Minimum	5.58E-05	2.19E-05	4.98E-05	0.00E+00	2.21E-06	1.43E-05
Maximum	4.17E-04	9.04E-05	2.01E-04	0.00E+00	2.91E-03	1.51E-04
Sum	1.43E-01	4.53E-02	9.43E-02	0.00E+00	2.93E-02	4.49E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	2.85E-06	6.64E-07	1.45E-06	0.00E+00	8.53E-06	1.05E-06

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.73E-04	1.15E-05	1.72E-05	2.59E-04	3.05E-05	4.40E-05
Standard Error	3.83E-05	2.61E-07	2.36E-07	4.76E-06	2.41E-07	3.65E-07
Median	1.68E-04	9.34E-06	1.58E-05	2.28E-04	2.96E-05	4.24E-05
Standard Deviation	1.21E-03	8.26E-06	7.46E-06	1.50E-04	7.61E-06	1.15E-05
Sample Variance	1.47E-06	6.83E-11	5.56E-11	2.26E-08	5.79E-11	1.33E-10
Kurtosis	8.98E+02	1.82E+01	1.44E+01	3.10E+01	6.72E-01	9.22E-01
Skewness	2.93E+01	3.38E+00	2.47E+00	3.93E+00	6.98E-01	7.83E-01
Range	3.75E-02	9.31E-05	8.26E-05	2.07E-03	4.69E-05	7.47E-05
Minimum	4.03E-05	9.66E-07	4.37E-06	5.97E-05	1.42E-05	2.06E-05
Maximum	3.75E-02	9.41E-05	8.70E-05	2.13E-03	6.11E-05	9.54E-05
Sum	2.73E-01	1.15E-02	1.72E-02	2.59E-01	3.05E-02	4.40E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	7.51E-05	5.13E-07	4.63E-07	9.33E-06	4.72E-07	7.16E-07

Table G-9 ADD Inhalation of Mo for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	2.78E-06	9.38E-06	1.57E-05	2.54E-06	1.77E-07	1.31E-05
Standard Error	2.15E-08	2.37E-08	5.00E-08	4.71E-07	2.06E-08	1.25E-07
Median	2.73E-06	9.32E-06	1.57E-05	1.80E-06	5.93E-08	1.23E-05
Standard Deviation	6.81E-07	7.49E-07	1.58E-06	1.49E-05	6.53E-07	3.94E-06
Sample Variance	4.64E-13	5.61E-13	2.50E-12	2.21E-10	4.26E-13	1.56E-11
Kurtosis	3.63E+00	1.52E-01	1.08E-03	9.83E+02	1.05E+02	6.22E+00
Skewness	1.16E+00	3.13E-01	2.42E-01	3.12E+01	9.59E+00	1.83E+00
Range	5.63E-06	5.27E-06	9.90E-06	4.70E-04	9.47E-06	3.14E-05
Minimum	1.32E-06	7.28E-06	1.14E-05	6.91E-07	5.93E-10	6.51E-06
Maximum	6.95E-06	1.25E-05	2.13E-05	4.71E-04	9.47E-06	3.79E-05
Sum	2.78E-03	9.38E-03	1.57E-02	2.54E-03	1.77E-04	1.31E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.23E-08	4.65E-08	9.81E-08	9.23E-07	4.05E-08	2.45E-07

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	3.43E-05	6.74E-06	7.49E-06	3.79E-05	7.18E-06	9.11E-06
Standard Error	1.18E-06	2.79E-07	7.85E-08	1.26E-06	2.61E-08	4.13E-08
Median	2.69E-05	5.33E-06	7.00E-06	3.20E-05	7.09E-06	8.96E-06
Standard Deviation	3.72E-05	8.81E-06	2.48E-06	3.97E-05	8.25E-07	1.31E-06
Sample Variance	1.38E-09	7.77E-11	6.16E-12	1.58E-09	6.80E-13	1.71E-12
Kurtosis	1.12E+02	2.87E+02	8.42E+00	3.56E+02	3.47E-01	7.52E-01
Skewness	8.98E+00	1.45E+01	2.13E+00	1.68E+01	4.86E-01	6.23E-01
Range	6.18E-04	2.05E-04	2.37E-05	9.65E-04	6.33E-06	8.48E-06
Minimum	7.38E-06	2.03E-06	3.42E-06	1.37E-05	4.99E-06	5.96E-06
Maximum	6.26E-04	2.07E-04	2.72E-05	9.78E-04	1.13E-05	1.44E-05
Sum	3.43E-02	6.74E-03	7.49E-03	3.79E-02	7.18E-03	9.11E-03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.31E-06	5.47E-07	1.54E-07	2.46E-06	5.12E-08	8.10E-08

Table G-10 EHQ of Mo for Terrestrial Plants and Aquatic Species at APG

Statistical data	*Terrestrial Plants*			*Aquatic Plants*		
	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	1.72E+01	1.76E+01	1.77E+01	4.88E-03	4.80E-03	4.82E-03
Standard Error	4.88E-01	5.68E-01	5.97E-01	3.51E-05	3.47E-05	3.49E-05
Median	1.28E+01	1.30E+01	1.29E+01	4.76E-03	4.69E-03	4.67E-03
Standard Deviation	1.54E+01	1.80E+01	1.89E+01	1.11E-03	1.10E-03	1.11E-03
Sample Variance	2.38E+02	3.22E+02	3.56E+02	1.23E-06	1.20E-06	1.22E-06
Kurtosis	1.44E+01	4.05E+01	7.66E+01	3.27E+00	1.22E+00	4.59E-01
Skewness	3.05E+00	4.92E+00	6.16E+00	1.05E+00	7.71E-01	6.97E-01
Range	1.43E+02	2.32E+02	3.24E+02	1.02E-02	7.70E-03	6.77E-03
Minimum	8.38E-01	1.01E+00	1.13E+00	2.50E-03	2.45E-03	2.28E-03
Maximum	1.44E+02	2.33E+02	3.25E+02	1.27E-02	1.02E-02	9.05E-03
Sum	1.72E+04	1.76E+04	1.77E+04	4.88E+00	4.80E+00	4.82E+00
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	9.57E-01	1.11E+00	1.17E+00	6.89E-05	6.80E-05	6.86E-05

Statistical data	*Aquatic Animals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	3.46E-05	3.45E-05	2.98E-02	3.46E-05
Standard Error	2.60E-07	2.56E-07	2.18E-04	2.59E-07
Median	3.00E-05	3.00E-05	2.90E-02	3.00E-05
Standard Deviation	8.21E-06	8.10E-06	6.89E-03	8.18E-06
Sample Variance	6.75E-11	6.56E-11	4.75E-05	6.69E-11
Kurtosis	4.71E-01	7.77E-01	6.45E-01	1.35E+00
Skewness	4.80E-01	6.34E-01	7.06E-01	6.93E-01
Range	5.00E-05	5.00E-05	4.45E-02	7.00E-05
Minimum	2.00E-05	2.00E-05	1.42E-02	1.00E-05
Maximum	7.00E-05	7.00E-05	5.87E-02	8.00E-05
Sum	3.46E-02	3.45E-02	2.98E+01	3.46E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	5.10E-07	5.03E-07	4.28E-04	5.08E-07

Table G-11 Cp of Mo for Terrestrial Plants and Aquatic Species at APG

	Terrestrial Plants			*Aquatic Plants*		
Statistical data	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	3.44E+00	3.52E+00	3.54E+00	2.93E+03	2.88E+03	2.89E+03
Standard Error	9.75E-02	1.14E-01	1.19E-01	2.11E+01	2.08E+01	2.10E+01
Median	2.57E+00	2.60E+00	2.58E+00	2.85E+03	2.81E+03	2.80E+03
Standard Deviation	3.08E+00	3.59E+00	3.78E+00	6.66E+02	6.58E+02	6.63E+02
Sample Variance	9.51E+00	1.29E+01	1.43E+01	4.44E+05	4.32E+05	4.40E+05
Kurtosis	1.44E+01	4.05E+01	7.66E+01	3.27E+00	1.22E+00	4.59E-01
Skewness	3.05E+00	4.92E+00	6.16E+00	1.05E+00	7.71E-01	6.97E-01
Range	2.85E+01	4.65E+01	6.48E+01	6.11E+03	4.62E+03	4.06E+03
Minimum	1.68E-01	2.01E-01	2.27E-01	1.50E+03	1.47E+03	1.37E+03
Maximum	2.87E+01	4.67E+01	6.50E+01	7.61E+03	6.09E+03	5.43E+03
Sum	3.44E+03	3.52E+03	3.54E+03	2.93E+06	2.88E+06	2.89E+06
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.91E-01	2.23E-01	2.34E-01	4.13E+01	4.08E+01	4.11E+01

Statistical data	*Aquatic Animals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	1.44E+00	1.44E+00	1.45E+00	1.44E+00
Standard Error	1.62E-02	1.79E-02	1.70E-02	1.74E-02
Median	1.37E+00	1.35E+00	1.35E+00	1.34E+00
Standard Deviation	5.13E-01	5.66E-01	5.38E-01	5.51E-01
Sample Variance	2.63E-01	3.21E-01	2.90E-01	3.04E-01
Kurtosis	1.06E+00	4.73E+00	1.29E+00	2.02E+00
Skewness	8.81E-01	1.52E+00	1.02E+00	1.12E+00
Range	3.20E+00	4.89E+00	3.40E+00	3.99E+00
Minimum	3.72E-01	4.60E-01	4.58E-01	4.36E-01
Maximum	3.57E+00	5.35E+00	3.86E+00	4.42E+00
Sum	1.44E+03	1.44E+03	1.45E+03	1.44E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.18E-02	3.51E-02	3.34E-02	3.42E-02

Table G-12 EHQ of Ta for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	3.09E-04	3.58E-05	3.36E-03	3.54E-04	1.66E-03	9.48E-01
Standard Error	9.36E-06	4.01E-07	2.55E-05	1.97E-05	5.56E-04	1.01E-02
Median	1.63E-04	3.45E-05	3.24E-03	2.79E-04	3.41E-04	8.91E-01
Standard Deviation	2.96E-04	1.27E-05	8.07E-04	6.23E-04	1.76E-02	3.18E-01
Sample Variance	8.76E-08	1.60E-10	6.51E-07	3.89E-07	3.09E-04	1.01E-01
Kurtosis	5.40E+00	1.75E-01	1.08E+00	7.65E+02	3.44E+02	3.35E+00
Skewness	2.09E+00	5.21E-01	8.63E-01	2.61E+01	1.83E+01	1.44E+00
Range	2.06E-03	7.39E-05	5.09E-03	1.87E-02	3.58E-01	2.43E+00
Minimum	3.37E-05	6.20E-06	1.53E-03	9.56E-05	7.60E-05	3.68E-01
Maximum	2.09E-03	8.01E-05	6.62E-03	1.88E-02	3.58E-01	2.80E+00
Sum	3.09E-01	3.58E-02	3.36E+00	3.54E-01	1.66E+00	9.48E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.84E-05	7.86E-07	5.01E-05	3.87E-05	1.09E-03	1.97E-02

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	7.17E-01	1.03E+00	2.36E+00	6.34E-01	1.02E-03	3.58E-03
Standard Error	5.09E-02	3.58E-02	3.02E-02	1.17E-02	8.15E-06	2.77E-05
Median	5.21E-01	8.37E-01	2.18E+00	5.61E-01	9.79E-04	3.49E-03
Standard Deviation	1.61E+00	1.13E+00	9.56E-01	3.69E-01	2.58E-04	8.76E-04
Sample Variance	2.59E+00	1.28E+00	9.13E-01	1.36E-01	6.64E-08	7.67E-07
Kurtosis	3.33E+02	3.04E+02	4.17E+00	1.68E+02	6.82E-01	5.91E-01
Skewness	1.72E+01	1.45E+01	1.56E+00	9.42E+00	7.49E-01	6.92E-01
Range	3.45E+01	2.71E+01	7.34E+00	7.83E+00	1.65E-03	5.97E-03
Minimum	1.24E-01	2.14E-01	4.32E-01	2.27E-01	3.84E-04	1.36E-03
Maximum	3.46E+01	2.73E+01	7.78E+00	8.06E+00	2.03E-03	7.33E-03
Sum	7.17E+02	1.03E+03	2.36E+03	6.34E+02	1.02E+00	3.58E+00
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	9.98E-02	7.02E-02	5.93E-02	2.29E-02	1.60E-05	5.43E-05

Table G-13 ADD Ingestion of Ta for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	3.36E-03	3.46E-04	3.82E-02	4.03E-03	1.89E-02	1.35E-01
Standard Error	1.07E-04	4.57E-06	2.91E-04	2.25E-04	6.34E-03	1.44E-03
Median	1.68E-03	3.33E-04	3.67E-02	3.17E-03	3.84E-03	1.27E-01
Standard Deviation	3.37E-03	1.44E-04	9.19E-03	7.11E-03	2.00E-01	4.55E-02
Sample Variance	1.14E-05	2.09E-08	8.45E-05	5.05E-05	4.02E-02	2.07E-03
Kurtosis	5.41E+00	1.69E-01	1.07E+00	7.65E+02	3.44E+02	3.35E+00
Skewness	2.09E+00	5.38E-01	8.63E-01	2.61E+01	1.83E+01	1.44E+00
Range	2.34E-02	8.17E-04	5.79E-02	2.13E-01	4.08E+00	3.48E-01
Minimum	2.84E-04	2.15E-05	1.73E-02	1.09E-03	8.49E-04	5.25E-02
Maximum	2.37E-02	8.39E-04	7.53E-02	2.14E-01	4.08E+00	4.00E-01
Sum	3.36E+00	3.46E-01	3.82E+01	4.03E+00	1.89E+01	1.35E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.09E-04	8.96E-06	5.70E-04	4.41E-04	1.24E-02	2.82E-03

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.79E-01	5.65E-02	2.10E-01	3.23E-01	1.16E-02	4.07E-02
Standard Error	1.98E-02	1.97E-03	2.69E-03	5.95E-03	9.29E-05	3.16E-04
Median	2.02E-01	4.60E-02	1.94E-01	2.86E-01	1.11E-02	3.97E-02
Standard Deviation	6.26E-01	6.22E-02	8.51E-02	1.88E-01	2.94E-03	9.98E-03
Sample Variance	3.92E-01	3.87E-03	7.23E-03	3.54E-02	8.63E-06	9.97E-05
Kurtosis	3.33E+02	3.04E+02	4.17E+00	1.68E+02	6.84E-01	5.91E-01
Skewness	1.72E+01	1.45E+01	1.56E+00	9.42E+00	7.49E-01	6.92E-01
Range	1.34E+01	1.49E+00	6.54E-01	3.99E+00	1.88E-02	6.80E-02
Minimum	4.74E-02	1.17E-02	3.85E-02	1.16E-01	4.33E-03	1.54E-02
Maximum	1.35E+01	1.50E+00	6.92E-01	4.11E+00	2.31E-02	8.35E-02
Sum	2.79E+02	5.65E+01	2.10E+02	3.23E+02	1.16E+01	4.07E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.88E-02	3.86E-03	5.28E-03	1.17E-02	1.82E-04	6.20E-04

Table G-14 ADD dermal Absorption of Ta for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	1.65E-04	5.19E-05	1.08E-04	0.00E+00	2.79E-05	5.05E-05
Standard Error	1.61E-06	3.76E-07	8.04E-07	0.00E+00	3.35E-06	6.21E-07
Median	1.57E-04	5.06E-05	1.06E-04	0.00E+00	1.23E-05	4.70E-05
Standard Deviation	5.09E-05	1.19E-05	2.54E-05	0.00E+00	1.06E-04	1.96E-05
Sample Variance	2.59E-09	1.41E-10	6.46E-10	0.00E+00	1.13E-08	3.86E-10
Kurtosis	2.92E+00	1.20E+00	2.34E-01	0.00E+00	4.77E+02	1.03E+01
Skewness	1.17E+00	7.21E-01	5.50E-01	0.00E+00	1.94E+01	1.92E+00
Range	4.12E-04	9.00E-05	1.65E-04	0.00E+00	2.80E-03	2.25E-04
Minimum	5.56E-05	2.38E-05	4.72E-05	0.00E+00	2.80E-06	1.76E-05
Maximum	4.67E-04	1.14E-04	2.12E-04	0.00E+00	2.80E-03	2.43E-04
Sum	1.65E-01	5.19E-02	1.08E-01	0.00E+00	2.79E-02	5.05E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	3.16E-06	7.37E-07	1.58E-06	0.00E+00	6.58E-06	1.22E-06

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.55E-04	1.37E-05	2.14E-05	3.04E-04	3.48E-05	4.88E-05
Standard Error	1.34E-05	3.89E-07	1.47E-06	6.09E-06	2.84E-07	4.29E-07
Median	1.93E-04	1.11E-05	1.83E-05	2.57E-04	3.37E-05	4.70E-05
Standard Deviation	4.25E-04	1.23E-05	4.65E-05	1.93E-04	8.97E-06	1.36E-05
Sample Variance	1.80E-07	1.51E-10	2.16E-09	3.71E-08	8.05E-11	1.84E-10
Kurtosis	4.21E+02	1.17E+02	9.26E+02	4.75E+01	1.62E+00	7.11E+00
Skewness	1.83E+01	8.32E+00	2.99E+01	4.96E+00	1.00E+00	1.59E+00
Range	1.08E-02	2.31E-04	1.46E-03	2.87E-03	6.54E-05	1.45E-04
Minimum	2.66E-05	1.45E-06	5.62E-06	7.38E-05	1.53E-05	2.22E-05
Maximum	1.09E-02	2.32E-04	1.46E-03	2.94E-03	8.07E-05	1.67E-04
Sum	2.55E-01	1.37E-02	2.14E-02	3.04E-01	3.48E-02	4.88E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.64E-05	7.64E-07	2.89E-06	1.20E-05	5.57E-07	8.43E-07

Table G-15 ADD Inhalation of Ta for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	3.16E-06	1.07E-05	1.77E-05	2.48E-06	1.50E-07	1.45E-05
Standard Error	2.60E-08	3.73E-08	7.04E-08	6.59E-08	2.73E-08	1.41E-07
Median	3.05E-06	1.06E-05	1.76E-05	2.06E-06	6.51E-08	1.37E-05
Standard Deviation	8.22E-07	1.18E-06	2.23E-06	2.09E-06	8.62E-07	4.45E-06
Sample Variance	6.75E-13	1.39E-12	4.96E-12	4.35E-12	7.44E-13	1.98E-11
Kurtosis	1.90E+00	-4.53E-04	8.86E-02	1.86E+02	7.64E+02	8.50E+00
Skewness	9.92E-01	2.51E-01	3.16E-01	1.10E+01	2.63E+01	1.94E+00
Range	5.61E-06	7.28E-06	1.53E-05	4.40E-05	2.56E-05	4.72E-05
Minimum	1.53E-06	7.66E-06	1.13E-05	6.66E-07	2.52E-09	5.44E-06
Maximum	7.15E-06	1.49E-05	2.66E-05	4.46E-05	2.56E-05	5.26E-05
Sum	3.16E-03	1.07E-02	1.77E-02	2.48E-03	1.50E-04	1.45E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	5.10E-08	7.32E-08	1.38E-07	1.29E-07	5.35E-08	2.76E-07

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	4.38E-05	7.65E-06	8.51E-06	4.22E-05	8.14E-06	1.04E-05
Standard Error	2.29E-06	4.07E-07	8.58E-08	1.38E-06	3.69E-08	5.48E-08
Median	3.17E-05	5.89E-06	8.00E-06	3.65E-05	8.04E-06	1.02E-05
Standard Deviation	7.24E-05	1.29E-05	2.71E-06	4.36E-05	1.17E-06	1.73E-06
Sample Variance	5.24E-09	1.65E-10	7.36E-12	1.90E-09	1.36E-12	3.01E-12
Kurtosis	1.61E+02	5.04E+02	4.12E+00	6.76E+02	4.67E-02	8.42E-01
Skewness	1.13E+01	2.01E+01	1.51E+00	2.38E+01	4.94E-01	7.13E-01
Range	1.37E-03	3.47E-04	2.09E-05	1.28E-03	6.94E-06	1.26E-05
Minimum	1.03E-05	1.67E-06	3.22E-06	1.57E-05	5.34E-06	5.96E-06
Maximum	1.38E-03	3.48E-04	2.42E-05	1.29E-03	1.23E-05	1.86E-05
Sum	4.38E-02	7.65E-03	8.51E-03	4.22E-02	8.14E-03	1.04E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.49E-06	7.98E-07	1.68E-07	2.71E-06	7.25E-08	1.08E-07

Table G-15 EHQ of Ta for Terrestrial Plants and Aquatic Species at APG

Statistical data	*Terrestrial Plants*			*Aquatic Plants*		
	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	2.95E-01	2.90E-01	2.83E-01	1.02E-03	1.02E-03	1.03E-03
Standard Error	5.38E-02	3.40E-02	3.80E-02	7.26E-06	7.08E-06	7.52E-06
Median	1.34E-01	1.36E-01	1.23E-01	9.90E-04	1.00E-03	1.00E-03
Standard Deviation	1.70E+00	1.07E+00	1.20E+00	2.30E-04	2.24E-04	2.38E-04
Sample Variance	2.90E+00	1.15E+00	1.45E+00	5.28E-08	5.02E-08	5.65E-08
Kurtosis	8.79E+02	5.56E+02	6.71E+02	5.07E-01	8.16E-01	6.45E-01
Skewness	2.88E+01	2.14E+01	2.42E+01	5.88E-01	7.45E-01	7.06E-01
Range	5.23E+01	2.95E+01	3.46E+01	1.54E-03	1.59E-03	1.53E-03
Minimum	6.00E-03	4.00E-03	3.00E-03	5.10E-04	5.40E-04	4.90E-04
Maximum	5.23E+01	2.95E+01	3.46E+01	2.05E-03	2.13E-03	2.02E-03
Sum	2.95E+02	2.90E+02	2.83E+02	1.02E+00	1.02E+00	1.03E+00
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	1.06E-01	6.66E-02	7.46E-02	1.43E-05	1.39E-05	1.48E-05

Statistical data	*Aquatic Animals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	1.08E-02	1.09E-02	1.15E-02	1.09E-02
Standard Error	7.71E-05	7.52E-05	8.43E-05	7.73E-05
Median	1.05E-02	1.06E-02	1.12E-02	1.06E-02
Standard Deviation	2.44E-03	2.38E-03	2.67E-03	2.44E-03
Sample Variance	5.95E-06	5.66E-06	7.11E-06	5.97E-06
Kurtosis	5.04E-01	8.21E-01	6.47E-01	1.20E+00
Skewness	5.88E-01	7.46E-01	7.07E-01	7.67E-01
Range	1.63E-02	1.70E-02	1.72E-02	2.02E-02
Minimum	5.40E-03	5.69E-03	5.48E-03	4.54E-03
Maximum	2.17E-02	2.27E-02	2.27E-02	2.47E-02
Sum	1.08E+01	1.09E+01	1.15E+01	1.09E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	1.51E-04	1.48E-04	1.65E-04	1.52E-04

Table G-16 Cp of Ta for Terrestrial Plants and Aquatic Species at APG

Statistical data	*Terrestrial Plants*			*Aquatic Plants*		
	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	2.95E-01	2.90E-01	2.83E-01	7.60E+00	7.61E+00	7.64E+00
Standard Error	5.38E-02	3.40E-02	3.80E-02	5.40E-02	5.27E-02	5.59E-02
Median	1.34E-01	1.36E-01	1.23E-01	7.35E+00	7.41E+00	7.44E+00
Standard Deviation	1.70E+00	1.07E+00	1.20E+00	1.71E+00	1.67E+00	1.77E+00
Sample Variance	2.90E+00	1.15E+00	1.45E+00	2.91E+00	2.78E+00	3.13E+00
Kurtosis	8.79E+02	5.56E+02	6.71E+02	4.79E-01	7.99E-01	6.41E-01
Skewness	2.88E+01	2.14E+01	2.42E+01	5.79E-01	7.48E-01	7.04E-01
Range	5.23E+01	2.95E+01	3.46E+01	1.14E+01	1.18E+01	1.15E+01
Minimum	6.00E-03	4.00E-03	3.00E-03	3.80E+00	3.99E+00	3.64E+00
Maximum	5.23E+01	2.95E+01	3.46E+01	1.52E+01	1.58E+01	1.51E+01
Sum	2.95E+02	2.90E+02	2.83E+02	7.60E+03	7.61E+03	7.64E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.06E-01	6.66E-02	7.46E-02	1.06E-01	1.04E-01	1.10E-01

Statistical data	*Aquatic Animals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	1.08E-02	1.09E-02	1.15E-02	1.09E-02
Standard Error	7.71E-05	7.52E-05	8.43E-05	7.73E-05
Median	1.05E-02	1.06E-02	1.12E-02	1.06E-02
Standard Deviation	2.44E-03	2.38E-03	2.67E-03	2.44E-03
Sample Variance	5.95E-06	5.66E-06	7.11E-06	5.97E-06
Kurtosis	5.04E-01	8.21E-01	6.47E-01	1.20E+00
Skewness	5.88E-01	7.46E-01	7.07E-01	7.67E-01
Range	1.63E-02	1.70E-02	1.72E-02	2.02E-02
Minimum	5.40E-03	5.69E-03	5.48E-03	4.54E-03
Maximum	2.17E-02	2.27E-02	2.27E-02	2.47E-02
Sum	1.08E+01	1.09E+01	1.15E+01	1.09E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.51E-04	1.48E-04	1.65E-04	1.52E-04

Table G-18 EHQ of DU for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	1.05E-02	8.75E-06	1.07E-03	1.85E-03	4.35E-03	1.74E-02
Standard Error	8.60E-05	4.21E-07	6.67E-05	2.39E-04	6.33E-04	1.14E-03
Median	9.58E-03	4.53E-06	4.40E-04	6.92E-04	1.97E-03	7.70E-03
Standard Deviation	2.72E-03	1.33E-05	2.11E-03	7.54E-03	2.00E-02	3.61E-02
Sample Variance	7.40E-06	1.77E-10	4.45E-06	5.69E-05	4.01E-04	1.31E-03
Kurtosis	4.41E+01	3.09E+01	6.49E+01	3.13E+02	6.47E+02	7.21E+01
Skewness	5.66E+00	4.77E+00	6.81E+00	1.66E+01	2.38E+01	7.36E+00
Range	3.55E-02	1.48E-04	2.88E-02	1.61E-01	5.69E-01	5.16E-01
Minimum	9.30E-03	1.69E-07	1.20E-04	2.39E-04	1.40E-03	1.88E-03
Maximum	4.48E-02	1.48E-04	2.89E-02	1.62E-01	5.70E-01	5.18E-01
Sum	1.05E+01	8.75E-03	1.07E+00	1.85E+00	4.35E+00	1.74E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.69E-04	8.27E-07	1.31E-04	4.68E-04	1.24E-03	2.24E-03

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.79E-02	1.12E-02	3.47E-02	7.23E-02	2.28E-04	1.07E-03
Standard Error	2.42E-03	1.47E-03	2.98E-03	2.54E-03	1.48E-05	8.37E-05
Median	1.17E-02	4.20E-03	1.19E-02	5.43E-02	9.00E-05	4.24E-04
Standard Deviation	7.66E-02	4.65E-02	9.42E-02	8.03E-02	4.67E-04	2.65E-03
Sample Variance	5.87E-03	2.16E-03	8.88E-03	6.45E-03	2.18E-07	7.00E-06
Kurtosis	2.23E+02	4.29E+02	1.38E+02	3.72E+02	6.73E+01	9.93E+01
Skewness	1.32E+01	1.90E+01	1.01E+01	1.62E+01	6.83E+00	8.74E+00
Range	1.51E+00	1.17E+00	1.70E+00	2.00E+00	6.53E-03	4.05E-02
Minimum	2.37E-03	6.83E-04	9.11E-04	4.57E-02	5.44E-06	9.38E-05
Maximum	1.51E+00	1.17E+00	1.70E+00	2.05E+00	6.53E-03	4.06E-02
Sum	2.79E+01	1.12E+01	3.47E+01	7.23E+01	2.28E-01	1.07E+00
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.75E-03	2.88E-03	5.85E-03	4.98E-03	2.90E-05	1.64E-04

Table G-19 ADD Ingestion of DU for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	9.35E-03	1.07E-04	1.52E-02	1.67E-03	3.91E-03	4.26E-02
Standard Error	7.71E-05	5.92E-06	9.55E-04	2.15E-04	5.70E-04	2.80E-03
Median	8.57E-03	4.66E-05	6.27E-03	6.23E-04	1.76E-03	1.89E-02
Standard Deviation	2.44E-03	1.87E-04	3.02E-02	6.79E-03	1.80E-02	8.85E-02
Sample Variance	5.94E-06	3.50E-08	9.12E-04	4.61E-05	3.25E-04	7.84E-03
Kurtosis	4.50E+01	3.32E+01	6.50E+01	3.13E+02	6.47E+02	7.21E+01
Skewness	5.73E+00	5.02E+00	6.82E+00	1.66E+01	2.38E+01	7.36E+00
Range	3.20E-02	2.07E-03	4.12E-01	1.45E-01	5.12E-01	1.26E+00
Minimum	8.37E-03	1.64E-06	1.71E-03	2.15E-04	1.26E-03	4.59E-03
Maximum	4.04E-02	2.07E-03	4.14E-01	1.45E-01	5.13E-01	1.27E+00
Sum	9.35E+00	1.07E-01	1.52E+01	1.67E+00	3.91E+00	4.26E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.51E-04	1.16E-05	1.87E-03	4.21E-04	1.12E-03	5.49E-03

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.24E-03	2.18E-02	7.58E-02	2.40E-01	3.25E-03	1.53E-02
Standard Error	3.08E-04	2.86E-03	6.52E-03	8.44E-03	2.12E-04	1.20E-03
Median	7.81E-04	8.17E-03	2.59E-02	1.80E-01	1.28E-03	6.06E-03
Standard Deviation	9.73E-03	9.04E-02	2.06E-01	2.67E-01	6.69E-03	3.79E-02
Sample Variance	9.46E-05	8.18E-03	4.25E-02	7.12E-02	4.48E-05	1.43E-03
Kurtosis	2.21E+02	4.29E+02	1.38E+02	3.72E+02	6.72E+01	9.93E+01
Skewness	1.34E+01	1.90E+01	1.01E+01	1.62E+01	6.83E+00	8.74E+00
Range	2.02E-01	2.28E+00	3.71E+00	6.66E+00	9.35E-02	5.79E-01
Minimum	1.08E-04	1.32E-03	1.99E-03	1.52E-01	7.63E-05	1.34E-03
Maximum	2.02E-01	2.28E+00	3.71E+00	6.81E+00	9.35E-02	5.81E-01
Sum	2.24E+00	2.18E+01	7.58E+01	2.40E+02	3.25E+00	1.53E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	6.04E-04	5.61E-03	1.28E-02	1.66E-02	4.15E-04	2.35E-03

Table G-20 ADD Dermal Absorption of DU for Terrestrial Animals at APG

Statistical data	Lizards	Mallard	American kestrel	Eastern garter snake	Woodhouse's toad	Cottontail rabbit
Mean	5.95E-05	1.80E-05	3.80E-05	0.00E+00	8.91E-06	1.48E-05
Standard Error	6.38E-06	1.27E-06	2.48E-06	0.00E+00	1.20E-06	1.03E-06
Median	1.88E-05	5.85E-06	1.37E-05	0.00E+00	1.64E-06	5.64E-06
Standard Deviation	2.02E-04	4.02E-05	7.84E-05	0.00E+00	3.80E-05	3.24E-05
Sample Variance	4.07E-08	1.62E-09	6.15E-09	0.00E+00	1.44E-09	1.05E-09
Kurtosis	2.05E+02	5.97E+01	4.47E+01	#DIV/0!	2.39E+02	1.34E+02
Skewness	1.29E+01	6.52E+00	5.71E+00	#DIV/0!	1.35E+01	9.14E+00
Range	3.70E-03	5.12E-04	9.30E-04	0.00E+00	8.20E-04	6.14E-04
Minimum	8.20E-08	5.97E-08	1.10E-07	0.00E+00	1.02E-08	1.57E-08
Maximum	3.70E-03	5.12E-04	9.30E-04	0.00E+00	8.20E-04	6.14E-04
Sum	5.95E-02	1.80E-02	3.80E-02	0.00E+00	8.91E-03	1.48E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.25E-05	2.50E-06	4.87E-06	0.00E+00	2.36E-06	2.01E-06

Statistical data	White-footed mouse	White-tailed deer	Beaver	Indiana bat	Bald eagle	Barred owl
Mean	2.31E-04	4.87E-06	6.50E-06	8.96E-05	1.30E-05	1.65E-05
Standard Error	1.37E-04	4.86E-07	4.38E-07	7.95E-06	7.64E-07	1.06E-06
Median	2.40E-05	1.35E-06	2.20E-06	3.06E-05	4.54E-06	5.68E-06
Standard Deviation	4.33E-03	1.54E-05	1.39E-05	2.51E-04	2.42E-05	3.34E-05
Sample Variance	1.87E-05	2.36E-10	1.92E-10	6.31E-08	5.84E-10	1.12E-09
Kurtosis	9.82E+02	1.03E+02	8.45E+01	3.00E+02	2.13E+01	5.06E+01
Skewness	3.12E+01	9.19E+00	7.36E+00	1.46E+01	4.08E+00	5.81E+00
Range	1.36E-01	2.22E-04	2.24E-04	5.85E-03	2.26E-04	4.56E-04
Minimum	2.38E-07	1.42E-08	3.01E-08	4.70E-08	5.09E-08	2.39E-08
Maximum	1.36E-01	2.22E-04	2.24E-04	5.85E-03	2.26E-04	4.56E-04
Sum	2.31E-01	4.87E-03	6.50E-03	8.96E-02	1.30E-02	1.65E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.69E-04	9.54E-07	8.60E-07	1.56E-05	1.50E-06	2.07E-06

Table G-21 EHQ of DU for Terrestrial Plants and Aquatic Species at APG

Statistical data	*Terrestrial Plants*			*Aquatic Plants*		
	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	3.34E-02	2.68E-02	3.41E-02	8.07E-04	8.10E-04	8.72E-04
Standard Error	3.34E-03	1.81E-03	3.00E-03	4.36E-05	4.64E-05	4.95E-05
Median	8.00E-03	9.00E-03	8.00E-03	3.60E-04	3.90E-04	3.90E-04
Standard Deviation	1.06E-01	5.73E-02	9.47E-02	1.38E-03	1.47E-03	1.57E-03
Sample Variance	1.12E-02	3.28E-03	8.97E-03	1.90E-06	2.15E-06	2.45E-06
Kurtosis	1.54E+02	4.20E+01	8.78E+01	6.50E+01	1.10E+02	4.49E+01
Skewness	1.06E+01	5.58E+00	7.93E+00	6.31E+00	7.91E+00	5.58E+00
Range	1.99E+00	6.43E-01	1.52E+00	2.13E-02	2.69E-02	2.01E-02
Minimum	0.00E+00	0.00E+00	0.00E+00	1.00E-05	1.00E-05	1.00E-05
Maximum	1.99E+00	6.43E-01	1.52E+00	2.13E-02	2.69E-02	2.01E-02
Sum	3.34E+01	2.68E+01	3.41E+01	8.07E-01	8.10E-01	8.72E-01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	6.56E-03	3.55E-03	5.88E-03	8.56E-05	9.10E-05	9.72E-05

Statistical data	*Aquatic Animals*			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	7.69E-02	7.72E-02	8.31E-02	7.35E-02
Standard Error	4.15E-03	4.42E-03	4.72E-03	3.82E-03
Median	3.50E-02	3.70E-02	3.70E-02	3.70E-02
Standard Deviation	1.31E-01	1.40E-01	1.49E-01	1.21E-01
Sample Variance	1.73E-02	1.95E-02	2.23E-02	1.46E-02
Kurtosis	6.50E+01	1.10E+02	4.49E+01	4.03E+01
Skewness	6.31E+00	7.91E+00	5.58E+00	5.21E+00
Range	2.03E+00	2.56E+00	1.91E+00	1.48E+00
Minimum	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Maximum	2.03E+00	2.56E+00	1.91E+00	1.48E+00
Sum	7.69E+01	7.72E+01	8.31E+01	7.35E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	8.15E-03	8.67E-03	9.26E-03	7.50E-03

Table G-22 Cp of DU for Terrestrial Plants and Aquatic Species at APG

Statistical data	Terrestrial Plants			Aquatic Plants		
	Rushes	Slender blue flag	Fern	Periphyton	Phytoplankton	Watermillfoil
Mean	1.67E-02	1.34E-02	1.70E-02	7.42E-01	7.46E-01	8.02E-01
Standard Error	1.67E-03	9.05E-04	1.50E-03	4.00E-02	4.26E-02	4.56E-02
Median	4.00E-03	4.00E-03	4.00E-03	3.34E-01	3.53E-01	3.57E-01
Standard Deviation	5.29E-02	2.86E-02	4.74E-02	1.27E+00	1.35E+00	1.44E+00
Sample Variance	2.80E-03	8.20E-04	2.24E-03	1.60E+00	1.81E+00	2.08E+00
Kurtosis	1.54E+02	4.19E+01	8.77E+01	6.48E+01	1.08E+02	4.54E+01
Skewness	1.06E+01	5.57E+00	7.92E+00	6.29E+00	7.84E+00	5.60E+00
Range	9.95E-01	3.21E-01	7.58E-01	1.95E+01	2.46E+01	1.86E+01
Minimum	0.00E+00	0.00E+00	0.00E+00	8.10E-03	1.08E-02	6.40E-03
Maximum	9.95E-01	3.21E-01	7.58E-01	1.95E+01	2.46E+01	1.86E+01
Sum	1.67E+01	1.34E+01	1.70E+01	7.42E+02	7.46E+02	8.02E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.28E-03	1.78E-03	2.94E-03	7.85E-02	8.36E-02	8.94E-02

Statistical data	Aquatic Animals			
	MountainWhitefish	PacificLamprey	RainbowTrout(adults)	WhiteSturgeon
Mean	6.07E-02	1.62E-02	5.09E-03	1.48E-02
Standard Error	3.20E-03	8.96E-04	3.69E-04	7.32E-04
Median	2.75E-02	6.90E-03	1.70E-03	7.15E-03
Standard Deviation	1.01E-01	2.83E-02	1.17E-02	2.31E-02
Sample Variance	1.02E-02	8.03E-04	1.36E-04	5.35E-04
Kurtosis	6.13E+01	4.32E+01	1.48E+02	2.00E+01
Skewness	6.06E+00	5.30E+00	9.40E+00	3.90E+00
Range	1.55E+00	3.84E-01	2.30E-01	2.26E-01
Minimum	7.00E-04	2.00E-04	0.00E+00	2.00E-04
Maximum	1.55E+00	3.84E-01	2.30E-01	2.26E-01
Sum	6.07E+01	1.62E+01	5.09E+00	1.48E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	6.28E-03	1.76E-03	7.24E-04	1.44E-03

Table G-23 EHQ of Cr (VI) for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	5.52E-02	5.63E-02	6.28E-01	1.86E-01	3.37E-02	3.85E-02
Standard Error	3.83E-04	4.50E-04	1.64E-03	1.07E-03	6.13E-04	2.48E-04
Median	5.35E-02	5.43E-02	6.25E-01	1.82E-01	2.98E-02	3.74E-02
Standard Deviation	1.21E-02	1.42E-02	5.18E-02	3.40E-02	1.94E-02	7.84E-03
Sample Variance	1.47E-04	2.03E-04	2.68E-03	1.15E-03	3.76E-04	6.15E-05
Kurtosis	1.25E+00	5.17E+02	2.37E-01	2.80E-01	2.04E+00	7.32E-01
Skewness	9.01E-01	1.96E+01	4.68E-01	5.44E-01	1.28E+00	8.07E-01
Range	8.01E-02	3.94E-01	3.11E-01	2.21E-01	1.20E-01	5.17E-02
Minimum	2.86E-02	4.34E-02	5.00E-01	9.36E-02	6.35E-04	2.25E-02
Maximum	1.09E-01	4.38E-01	8.12E-01	3.15E-01	1.21E-01	7.41E-02
Sum	5.52E+01	5.63E+01	6.28E+02	1.86E+02	3.37E+01	3.85E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	7.51E-04	8.83E-04	3.21E-03	2.11E-03	1.20E-03	4.87E-04

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	7.01E-02	1.51E-01	3.51E-02	4.19E-02	5.00E-01
Standard Error	6.49E-04	2.63E-03	1.76E-04	4.08E-04	2.33E-03
Median	6.69E-02	1.12E-01	3.43E-02	3.92E-02	4.91E-01
Standard Deviation	2.05E-02	8.30E-02	5.56E-03	1.29E-02	7.38E-02
Sample Variance	4.21E-04	6.90E-03	3.09E-05	1.67E-04	5.44E-03
Kurtosis	7.27E+01	1.25E+01	1.82E+00	2.24E+01	8.46E-01
Skewness	5.11E+00	2.86E+00	9.68E-01	3.21E+00	6.48E-01
Range	3.75E-01	7.66E-01	4.49E-02	1.65E-01	4.77E-01
Minimum	3.21E-02	9.12E-02	2.27E-02	2.05E-02	3.18E-01
Maximum	4.07E-01	8.57E-01	6.76E-02	1.85E-01	7.95E-01
Sum	7.01E+01	1.51E+02	3.51E+01	4.19E+01	5.00E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	1.27E-03	5.15E-03	3.45E-04	8.01E-04	4.58E-03

Table G-24 ADD Ingestion of Cr(VI) for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	1.33E-01	4.82E-01	8.36E-02	2.48E-02	4.48E-03	6.67E-02
Standard Error	9.23E-04	3.86E-03	2.18E-04	1.43E-04	8.16E-05	4.29E-04
Median	1.29E-01	4.65E-01	8.31E-02	2.43E-02	3.96E-03	6.46E-02
Standard Deviation	2.92E-02	1.22E-01	6.88E-03	4.52E-03	2.58E-03	1.36E-02
Sample Variance	8.51E-04	1.49E-02	4.74E-05	2.04E-05	6.65E-06	1.84E-04
Kurtosis	1.25E+00	5.16E+02	2.37E-01	2.80E-01	2.04E+00	7.32E-01
Skewness	9.01E-01	1.96E+01	4.68E-01	5.44E-01	1.28E+00	8.07E-01
Range	1.93E-01	3.38E+00	4.14E-02	2.95E-02	1.60E-02	8.94E-02
Minimum	6.88E-02	3.71E-01	6.65E-02	1.24E-02	8.45E-05	3.89E-02
Maximum	2.62E-01	3.75E+00	1.08E-01	4.19E-02	1.61E-02	1.28E-01
Sum	1.33E+02	4.82E+02	8.36E+01	2.48E+01	4.48E+00	6.67E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.81E-03	7.57E-03	4.27E-04	2.80E-04	1.60E-04	8.42E-04

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	6.45E-02	2.01E-02	4.67E-03	2.74E-01	6.65E-02
Standard Error	5.97E-04	3.49E-04	2.34E-05	2.67E-03	3.10E-04
Median	6.16E-02	1.48E-02	4.56E-03	2.57E-01	6.53E-02
Standard Deviation	1.89E-02	1.10E-02	7.40E-04	8.46E-02	9.81E-03
Sample Variance	3.56E-04	1.22E-04	5.47E-07	7.15E-03	9.63E-05
Kurtosis	7.27E+01	1.25E+01	1.82E+00	2.24E+01	8.46E-01
Skewness	5.11E+00	2.86E+00	9.68E-01	3.21E+00	6.48E-01
Range	3.45E-01	1.02E-01	5.97E-03	1.08E+00	6.34E-02
Minimum	2.95E-02	1.21E-02	3.01E-03	1.34E-01	4.23E-02
Maximum	3.74E-01	1.14E-01	8.99E-03	1.21E+00	1.06E-01
Sum	6.45E+01	2.01E+01	4.67E+00	2.74E+02	6.65E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.17E-03	6.85E-04	4.59E-05	5.25E-03	6.09E-04

Table G-25 ADD Dermal Absorption of Cr (VI) for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	2.03E-05	1.43E-04	7.15E-05	2.33E-05	0.00E+00	1.92E-05
Standard Error	2.27E-07	3.91E-06	5.69E-07	1.68E-07	0.00E+00	1.95E-07
Median	1.90E-05	1.22E-04	6.91E-05	2.28E-05	0.00E+00	1.81E-05
Standard Deviation	7.17E-06	1.24E-04	1.80E-05	5.30E-06	0.00E+00	6.15E-06
Sample Variance	5.15E-11	1.53E-08	3.23E-10	2.81E-11	0.00E+00	3.79E-11
Kurtosis	6.61E+00	2.26E+02	1.02E+00	8.25E-01	#DIV/0!	2.50E+00
Skewness	1.65E+00	1.24E+01	8.20E-01	6.46E-01	#DIV/0!	1.18E+00
Range	6.82E-05	2.67E-03	1.17E-04	3.68E-05	0.00E+00	4.49E-05
Minimum	5.78E-06	4.09E-05	3.13E-05	1.12E-05	0.00E+00	6.37E-06
Maximum	7.40E-05	2.71E-03	1.48E-04	4.80E-05	0.00E+00	5.13E-05
Sum	2.03E-02	1.43E-01	7.15E-02	2.33E-02	0.00E+00	1.92E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.45E-07	7.67E-06	1.12E-06	3.29E-07	0.00E+00	3.82E-07

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	6.69E-06	0.00E+00	7.90E-05	1.08E-04	4.74E-05
Standard Error	2.79E-07	0.00E+00	7.69E-07	2.72E-06	4.45E-07
Median	5.88E-06	0.00E+00	7.52E-05	9.59E-05	4.56E-05
Standard Deviation	8.81E-06	0.00E+00	2.43E-05	8.61E-05	1.41E-05
Sample Variance	7.77E-11	0.00E+00	5.92E-10	7.42E-09	1.98E-10
Kurtosis	8.19E+02	#DIV/0!	2.92E+00	3.56E+01	1.88E+00
Skewness	2.73E+01	#DIV/0!	1.17E+00	3.75E+00	9.79E-01
Range	2.69E-04	0.00E+00	1.97E-04	1.26E-03	1.14E-04
Minimum	2.15E-06	0.00E+00	2.66E-05	1.45E-07	1.68E-05
Maximum	2.72E-04	0.00E+00	2.23E-04	1.26E-03	1.30E-04
Sum	6.69E-03	0.00E+00	7.90E-02	1.08E-01	4.74E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	5.47E-07	0.00E+00	1.51E-06	5.35E-06	8.73E-07

Table G-26 ADD Inhalation of Cr (VI) for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	6.23E-06	2.00E-05	1.12E-05	4.87E-06	8.75E-07	6.08E-06
Standard Error	5.51E-08	3.58E-07	1.77E-07	1.15E-08	2.80E-09	4.20E-08
Median	5.88E-06	1.78E-05	1.09E-05	4.86E-06	8.70E-07	5.87E-06
Standard Deviation	1.74E-06	1.13E-05	5.60E-06	3.65E-07	8.86E-08	1.33E-06
Sample Variance	3.04E-12	1.28E-10	3.14E-11	1.33E-13	7.85E-15	1.76E-12
Kurtosis	6.31E+00	6.63E+01	4.24E-01	1.49E-01	4.59E-01	3.50E+00
Skewness	1.79E+00	6.35E+00	5.61E-01	1.52E-01	3.66E-01	1.35E+00
Range	1.52E-05	1.73E-04	3.54E-05	2.48E-06	6.78E-07	1.05E-05
Minimum	3.07E-06	8.25E-06	7.50E-09	3.88E-06	6.20E-07	3.33E-06
Maximum	1.83E-05	1.81E-04	3.54E-05	6.36E-06	1.30E-06	1.39E-05
Sum	6.23E-03	2.00E-02	1.12E-02	4.87E-03	8.75E-04	6.08E-03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	1.08E-07	7.03E-07	3.48E-07	2.26E-08	5.50E-09	8.24E-08

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	3.13E-06	1.10E-06	1.51E-06	1.76E-05	8.07E-06
Standard Error	3.75E-08	1.64E-08	1.18E-08	3.64E-07	4.93E-08
Median	2.87E-06	9.91E-07	1.47E-06	1.55E-05	7.90E-06
Standard Deviation	1.19E-06	5.18E-07	3.73E-07	1.15E-05	1.56E-06
Sample Variance	1.41E-12	2.68E-13	1.39E-13	1.33E-10	2.43E-12
Kurtosis	5.21E+01	1.21E+01	1.83E+00	6.83E+00	1.12E+00
Skewness	4.64E+00	2.39E+00	9.62E-01	1.79E+00	8.43E-01
Range	1.92E-05	5.56E-06	2.57E-06	1.02E-04	1.04E-05
Minimum	1.56E-06	2.48E-07	7.08E-07	7.72E-08	4.75E-06
Maximum	2.08E-05	5.81E-06	3.28E-06	1.02E-04	1.51E-05
Sum	3.13E-03	1.10E-03	1.51E-03	1.76E-02	8.07E-03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	7.37E-08	3.22E-08	2.32E-08	7.15E-07	9.67E-08

Table G-27 EHQ of Cr (VI) for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	1.52E-01	5.43E-02	8.15E-02
Standard Error	4.03E-03	1.56E-03	2.40E-03
Median	1.15E-01	4.20E-02	5.80E-02
Standard Deviation	1.28E-01	4.94E-02	7.59E-02
Sample Variance	1.63E-02	2.44E-03	5.76E-03
Kurtosis	1.10E+01	2.62E+01	3.47E+01
Skewness	2.68E+00	3.89E+00	4.14E+00
Range	1.12E+00	5.80E-01	1.07E+00
Minimum	1.00E-02	3.00E-03	8.00E-03
Maximum	1.13E+00	5.83E-01	1.07E+00
Sum	1.52E+02	5.43E+01	8.15E+01
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	7.92E-03	3.06E-03	4.71E-03

Table G-28 Cp of Cr (VI) for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	1.67E-01	1.68E-01	1.71E-01
Standard Error	4.44E-03	4.84E-03	5.04E-03
Median	1.26E-01	1.32E-01	1.23E-01
Standard Deviation	1.40E-01	1.53E-01	1.59E-01
Sample Variance	1.97E-02	2.34E-02	2.54E-02
Kurtosis	1.10E+01	2.62E+01	3.47E+01
Skewness	2.68E+00	3.90E+00	4.14E+00
Range	1.23E+00	1.80E+00	2.24E+00
Minimum	1.10E-02	9.00E-03	1.60E-02
Maximum	1.24E+00	1.81E+00	2.25E+00
Sum	1.67E+02	1.68E+02	1.71E+02
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	8.71E-03	9.50E-03	9.89E-03

Table G- 29 EHQ of Mo for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises
Mean	3.31E+01	1.05E+01	1.80E-01	3.10E-02	2.68E-02
Standard Error	3.19E-01	7.30E-02	5.06E-04	1.60E-04	6.32E-04
Median	3.16E+01	1.02E+01	1.78E-01	3.06E-02	1.69E-02
Standard Deviation	1.01E+01	2.31E+00	1.60E-02	5.06E-03	2.00E-02
Sample Variance	1.02E+02	5.33E+00	2.56E-04	2.56E-05	4.00E-04
Kurtosis	6.31E+00	3.81E+02	1.01E+00	6.16E-01	2.49E+00
Skewness	1.71E+00	1.82E+01	7.89E-01	5.36E-01	1.53E+00
Range	9.39E+01	5.55E+01	1.13E-01	3.47E-02	1.30E-01
Minimum	1.37E+01	9.32E+00	1.46E-01	1.86E-02	5.19E-04
Maximum	1.08E+02	6.48E+01	2.59E-01	5.33E-02	1.30E-01
Sum	3.31E+04	1.05E+04	1.80E+02	3.10E+01	2.68E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	6.26E-01	1.43E-01	9.92E-04	3.14E-04	1.24E-03

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	4.54E+01	6.44E-03	7.16E-03	2.73E+01	5.06E-01
Standard Error	4.91E-01	2.40E-04	1.21E-05	4.26E-01	2.98E-03
Median	4.25E+01	3.66E-03	7.10E-03	2.48E+01	4.96E-01
Standard Deviation	1.55E+01	7.59E-03	3.84E-04	1.35E+01	9.43E-02
Sample Variance	2.41E+02	5.76E-05	1.48E-07	1.82E+02	8.89E-03
Kurtosis	5.89E+00	1.11E+02	1.30E+00	2.61E+02	1.66E+00
Skewness	1.72E+00	8.01E+00	9.33E-01	1.23E+01	7.89E-01
Range	1.36E+02	1.37E-01	2.77E-03	3.18E+02	7.36E-01
Minimum	1.62E+01	1.89E-03	6.35E-03	1.35E+01	2.83E-01
Maximum	1.52E+02	1.39E-01	9.12E-03	3.31E+02	1.02E+00
Sum	4.54E+04	6.44E+00	7.16E+00	2.73E+04	5.06E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	9.64E-01	4.71E-04	2.38E-05	8.36E-01	5.85E-03

Table G-30 ADD Ingestion of Mo for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	3.31E+00	3.88E+00	6.29E-01	1.09E-01	9.38E-02	3.14E-01
Standard Error	3.19E-02	2.70E-02	1.77E-03	5.60E-04	2.21E-03	1.54E-03
Median	3.16E+00	3.78E+00	6.23E-01	1.07E-01	5.90E-02	3.08E-01
Standard Deviation	1.01E+00	8.54E-01	5.60E-02	1.77E-02	7.00E-02	4.86E-02
Sample Variance	1.02E+00	7.30E-01	3.13E-03	3.14E-04	4.90E-03	2.37E-03
Kurtosis	6.31E+00	3.81E+02	1.01E+00	6.16E-01	2.49E+00	2.02E+00
Skewness	1.71E+00	1.82E+01	7.90E-01	5.36E-01	1.53E+00	9.81E-01
Range	9.39E+00	2.05E+01	3.96E-01	1.22E-01	4.54E-01	3.85E-01
Minimum	1.37E+00	3.45E+00	5.09E-01	6.49E-02	1.82E-03	2.09E-01
Maximum	1.08E+01	2.40E+01	9.05E-01	1.87E-01	4.56E-01	5.94E-01
Sum	3.31E+03	3.88E+03	6.29E+02	1.09E+02	9.38E+01	3.14E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	6.26E-02	5.30E-02	3.47E-03	1.10E-03	4.34E-03	3.02E-03

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	1.82E+00	2.26E-02	2.49E-02	7.64E+00	1.77E+00
Standard Error	1.97E-02	8.40E-04	4.26E-05	1.19E-01	1.04E-02
Median	1.70E+00	1.28E-02	2.47E-02	6.94E+00	1.74E+00
Standard Deviation	6.22E-01	2.66E-02	1.35E-03	3.77E+00	3.30E-01
Sample Variance	3.86E-01	7.05E-04	1.81E-06	1.42E+01	1.09E-01
Kurtosis	5.89E+00	1.11E+02	1.31E+00	2.61E+02	1.66E+00
Skewness	1.72E+00	8.01E+00	9.36E-01	1.23E+01	7.89E-01
Range	5.45E+00	4.80E-01	9.71E-03	8.90E+01	2.57E+00
Minimum	6.47E-01	6.62E-03	2.20E-02	3.79E+00	9.90E-01
Maximum	6.10E+00	4.87E-01	3.17E-02	9.28E+01	3.56E+00
Sum	1.82E+03	2.26E+01	2.49E+01	7.64E+03	1.77E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.86E-02	1.65E-03	8.36E-05	2.34E-01	2.05E-02

Table G-31 ADD Dermal Absorption of Mo for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	3.70E-05	2.63E-04	1.30E-04	4.31E-05	0.00E+00	3.50E-05
Standard Error	4.20E-07	7.95E-06	9.90E-07	3.16E-07	0.00E+00	3.48E-07
Median	3.45E-05	2.23E-04	1.27E-04	4.21E-05	0.00E+00	3.34E-05
Standard Deviation	1.33E-05	2.51E-04	3.13E-05	1.00E-05	0.00E+00	1.10E-05
Sample Variance	1.77E-10	6.31E-08	9.81E-10	1.00E-10	0.00E+00	1.21E-10
Kurtosis	5.90E+00	3.38E+02	3.17E-01	1.99E-01	#DIV/0!	1.79E+00
Skewness	1.67E+00	1.55E+01	5.79E-01	5.01E-01	#DIV/0!	9.93E-01
Range	1.26E-04	6.19E-03	1.99E-04	6.34E-05	0.00E+00	8.24E-05
Minimum	1.10E-05	7.33E-05	5.57E-05	2.05E-05	0.00E+00	1.40E-05
Maximum	1.37E-04	6.26E-03	2.55E-04	8.39E-05	0.00E+00	9.65E-05
Sum	3.70E-02	2.63E-01	1.30E-01	4.31E-02	0.00E+00	3.50E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	8.25E-07	1.56E-05	1.94E-06	6.21E-07	0.00E+00	6.82E-07

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	1.19E-05	0.00E+00	1.46E-04	2.11E-04	8.82E-05
Standard Error	2.15E-07	0.00E+00	1.52E-06	4.87E-06	8.87E-07
Median	1.09E-05	0.00E+00	1.40E-04	1.81E-04	8.38E-05
Standard Deviation	6.79E-06	0.00E+00	4.81E-05	1.54E-04	2.81E-05
Sample Variance	4.61E-11	0.00E+00	2.31E-09	2.37E-08	7.87E-10
Kurtosis	2.70E+02	#DIV/0!	7.97E+00	5.54E+00	3.25E+00
Skewness	1.23E+01	#DIV/0!	1.74E+00	1.76E+00	1.35E+00
Range	1.64E-04	0.00E+00	5.22E-04	1.36E-03	2.05E-04
Minimum	2.97E-06	0.00E+00	5.09E-05	4.50E-08	3.75E-05
Maximum	1.67E-04	0.00E+00	5.73E-04	1.36E-03	2.43E-04
Sum	1.19E-02	0.00E+00	1.46E-01	2.11E-01	8.82E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	4.22E-07	0.00E+00	2.99E-06	9.55E-06	1.74E-06

Table G-32 ADD Inhalation of Mo for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	1.17E-05	3.70E-05	2.04E-05	9.02E-06	1.61E-06	1.11E-05
Standard Error	1.03E-07	1.13E-06	3.17E-07	2.26E-08	5.35E-09	7.27E-08
Median	1.11E-05	3.23E-05	1.95E-05	8.99E-06	1.59E-06	1.08E-05
Standard Deviation	3.27E-06	3.56E-05	1.00E-05	7.14E-07	1.69E-07	2.30E-06
Sample Variance	1.07E-11	1.27E-09	1.01E-10	5.10E-13	2.87E-14	5.29E-12
Kurtosis	5.10E+00	6.56E+02	1.98E-01	-6.00E-02	7.52E-02	2.29E+00
Skewness	1.66E+00	2.33E+01	4.47E-01	2.41E-01	3.76E-01	1.05E+00
Range	2.56E-05	1.04E-03	6.14E-05	4.49E-06	1.08E-06	1.91E-05
Minimum	5.92E-06	1.43E-05	2.90E-08	6.68E-06	1.19E-06	5.39E-06
Maximum	3.15E-05	1.05E-03	6.14E-05	1.12E-05	2.27E-06	2.44E-05
Sum	1.17E-02	3.70E-02	2.04E-02	9.02E-03	1.61E-03	1.11E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.03E-07	2.21E-06	6.23E-07	4.43E-08	1.05E-08	1.43E-07

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	5.75E-06	2.07E-06	2.74E-06	3.17E-05	1.50E-05
Standard Error	6.11E-08	7.06E-08	2.09E-08	6.51E-07	9.23E-08
Median	5.40E-06	1.78E-06	2.67E-06	2.86E-05	1.46E-05
Standard Deviation	1.93E-06	2.23E-06	6.59E-07	2.06E-05	2.92E-06
Sample Variance	3.73E-12	4.99E-12	4.35E-13	4.24E-10	8.52E-12
Kurtosis	7.98E+00	5.38E+02	1.12E+00	4.36E+00	1.81E+00
Skewness	2.13E+00	2.04E+01	7.71E-01	1.36E+00	1.01E+00
Range	1.69E-05	6.23E-05	4.67E-06	1.89E-04	1.89E-05
Minimum	2.61E-06	2.08E-07	1.11E-06	6.56E-08	9.14E-06
Maximum	1.95E-05	6.25E-05	5.78E-06	1.89E-04	2.81E-05
Sum	5.75E-03	2.07E-03	2.74E-03	3.17E-02	1.50E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.20E-07	1.39E-07	4.09E-08	1.28E-06	1.81E-07

Table G-33 EHQ of Mo for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	1.72E+01	1.76E+01	1.77E+01
Standard Error	4.88E-01	5.68E-01	5.97E-01
Median	1.28E+01	1.30E+01	1.29E+01
Standard Deviation	1.54E+01	1.80E+01	1.89E+01
Sample Variance	2.38E+02	3.22E+02	3.56E+02
Kurtosis	1.44E+01	4.05E+01	7.66E+01
Skewness	3.05E+00	4.92E+00	6.16E+00
Range	1.43E+02	2.32E+02	3.24E+02
Minimum	8.38E-01	1.01E+00	1.13E+00
Maximum	1.44E+02	2.33E+02	3.25E+02
Sum	1.72E+04	1.76E+04	1.77E+04
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	9.57E-01	1.11E+00	1.17E+00

Table G-34 Cp of Mo for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	3.44E+00	3.52E+00	3.54E+00
Standard Error	9.75E-02	1.14E-01	1.19E-01
Median	2.57E+00	2.60E+00	2.58E+00
Standard Deviation	3.08E+00	3.59E+00	3.78E+00
Sample Variance	9.51E+00	1.29E+01	1.43E+01
Kurtosis	1.44E+01	4.05E+01	7.66E+01
Skewness	3.05E+00	4.92E+00	6.16E+00
Range	2.85E+01	4.65E+01	6.48E+01
Minimum	1.68E-01	2.01E-01	2.27E-01
Maximum	2.87E+01	4.67E+01	6.50E+01
Sum	3.44E+03	3.52E+03	3.54E+03
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.91E-01	2.23E-01	2.34E-01

Table G-35 EHQ of Ta for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	9.00E-01	6.02E-01	6.04E-03	3.74E-03	4.75E-04	9.88E-01
Standard Error	8.59E-03	1.03E-02	3.48E-05	2.45E-05	1.08E-05	8.13E-03
Median	8.55E-01	5.42E-01	5.87E-03	3.67E-03	3.59E-04	9.57E-01
Standard Deviation	2.72E-01	3.25E-01	1.10E-03	7.74E-04	3.40E-04	2.57E-01
Sample Variance	7.37E-02	1.06E-01	1.21E-06	5.99E-07	1.16E-07	6.60E-02
Kurtosis	5.63E+00	1.40E+02	7.14E-01	7.48E-01	5.80E+00	6.28E-01
Skewness	1.43E+00	8.19E+00	7.15E-01	5.93E-01	1.89E+00	7.78E-01
Range	2.89E+00	6.67E+00	6.76E-03	5.20E-03	3.09E-03	1.61E+00
Minimum	3.36E-01	2.03E-01	3.50E-03	1.82E-03	5.56E-06	4.96E-01
Maximum	3.22E+00	6.87E+00	1.03E-02	7.02E-03	3.10E-03	2.11E+00
Sum	9.00E+02	6.02E+02	6.04E+00	3.74E+00	4.75E-01	9.88E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.69E-02	2.02E-02	6.83E-05	4.80E-05	2.11E-05	1.59E-02

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	9.49E-01	1.65E-03	4.91E-04	5.57E-01	4.64E-03
Standard Error	9.83E-03	6.89E-05	4.48E-06	6.48E-03	2.97E-05
Median	8.96E-01	6.09E-04	4.69E-04	5.19E-01	4.52E-03
Standard Deviation	3.11E-01	2.18E-03	1.42E-04	2.05E-01	9.39E-04
Sample Variance	9.66E-02	4.75E-06	2.01E-08	4.20E-02	8.82E-07
Kurtosis	2.82E+01	9.61E+00	5.64E+00	7.62E+01	1.51E+00
Skewness	3.19E+00	2.60E+00	1.47E+00	5.44E+00	8.27E-01
Range	4.46E+00	1.89E-02	1.41E-03	3.67E+00	7.13E-03
Minimum	3.84E-01	2.42E-05	1.79E-04	2.79E-01	2.42E-03
Maximum	4.84E+00	1.90E-02	1.59E-03	3.95E+00	9.56E-03
Sum	9.49E+02	1.65E+00	4.91E-01	5.57E+02	4.64E+00
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.93E-02	1.35E-04	8.79E-06	1.27E-02	5.83E-05

Table G-36 ADD Ingestion of Ta Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	1.29E-01	3.07E-01	6.87E-02	4.26E-02	5.41E-03	1.02E-01
Standard Error	1.23E-03	5.25E-03	3.96E-04	2.79E-04	1.23E-04	8.37E-04
Median	1.22E-01	2.76E-01	6.67E-02	4.18E-02	4.09E-03	9.85E-02
Standard Deviation	3.88E-02	1.66E-01	1.25E-02	8.83E-03	3.88E-03	2.65E-02
Sample Variance	1.51E-03	2.76E-02	1.57E-04	7.79E-05	1.51E-05	7.00E-04
Kurtosis	5.63E+00	1.40E+02	7.14E-01	7.48E-01	5.80E+00	6.28E-01
Skewness	1.43E+00	8.19E+00	7.15E-01	5.93E-01	1.89E+00	7.78E-01
Range	4.13E-01	3.40E+00	7.71E-02	5.92E-02	3.52E-02	1.66E-01
Minimum	4.80E-02	1.03E-01	3.97E-02	2.07E-02	6.17E-05	5.11E-02
Maximum	4.61E-01	3.50E+00	1.17E-01	8.00E-02	3.53E-02	2.17E-01
Sum	1.29E+02	3.07E+02	6.87E+01	4.26E+01	5.41E+00	1.02E+02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	2.41E-03	1.03E-02	7.78E-04	5.48E-04	2.41E-04	1.64E-03

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	5.22E-02	1.88E-02	5.43E-03	2.16E-01	5.28E-02
Standard Error	5.41E-04	7.85E-04	5.10E-05	2.52E-03	3.39E-04
Median	4.92E-02	6.94E-03	5.18E-03	2.02E-01	5.14E-02
Standard Deviation	1.71E-02	2.48E-02	1.61E-03	7.97E-02	1.07E-02
Sample Variance	2.92E-04	6.17E-04	2.60E-06	6.35E-03	1.15E-04
Kurtosis	2.82E+01	9.61E+00	5.69E+00	7.62E+01	1.50E+00
Skewness	3.19E+00	2.60E+00	1.47E+00	5.44E+00	8.27E-01
Range	2.45E-01	2.16E-01	1.60E-02	1.43E+00	8.13E-02
Minimum	2.11E-02	2.74E-04	1.91E-03	1.08E-01	2.75E-02
Maximum	2.66E-01	2.16E-01	1.80E-02	1.54E+00	1.09E-01
Sum	5.22E+01	1.88E+01	5.43E+00	2.16E+02	5.28E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level(95.0%)	1.06E-03	1.54E-03	1.00E-04	4.95E-03	6.65E-04

Table G-37 ADD Dermal Absorption of Ta for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	4.27E-05	2.88E-04	1.48E-04	4.87E-05	0.00E+00	4.05E-05
Standard Error	5.09E-07	5.11E-06	1.16E-06	3.63E-07	0.00E+00	4.19E-07
Median	3.93E-05	2.55E-04	1.44E-04	4.75E-05	0.00E+00	3.89E-05
Standard Deviation	1.61E-05	1.62E-04	3.68E-05	1.15E-05	0.00E+00	1.32E-05
Sample Variance	2.59E-10	2.61E-08	1.35E-09	1.32E-10	0.00E+00	1.75E-10
Kurtosis	3.57E+00	4.98E+01	4.47E-01	8.01E-01	#DIV/0!	8.03E+00
Skewness	1.41E+00	4.73E+00	6.25E-01	7.05E-01	#DIV/0!	1.74E+00
Range	1.23E-04	2.55E-03	2.40E-04	7.84E-05	0.00E+00	1.44E-04
Minimum	1.28E-05	9.13E-05	7.18E-05	2.23E-05	0.00E+00	1.43E-05
Maximum	1.36E-04	2.64E-03	3.11E-04	1.01E-04	0.00E+00	1.58E-04
Sum	4.27E-02	2.88E-01	1.48E-01	4.87E-02	0.00E+00	4.05E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.00E-06	1.00E-05	2.28E-06	7.13E-07	0.00E+00	8.21E-07

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	1.39E-05	0.00E+00	1.63E-04	2.33E-04	1.00E-04
Standard Error	1.91E-07	0.00E+00	1.70E-06	5.33E-06	9.82E-07
Median	1.25E-05	0.00E+00	1.52E-04	2.02E-04	9.49E-05
Standard Deviation	6.06E-06	0.00E+00	5.36E-05	1.69E-04	3.11E-05
Sample Variance	3.67E-11	0.00E+00	2.88E-09	2.84E-08	9.65E-10
Kurtosis	5.74E+00	#DIV/0!	7.26E+00	7.02E+00	3.93E+00
Skewness	1.79E+00	#DIV/0!	1.82E+00	1.84E+00	1.34E+00
Range	5.23E-05	0.00E+00	5.16E-04	1.58E-03	2.73E-04
Minimum	4.14E-06	0.00E+00	6.20E-05	2.69E-06	3.81E-05
Maximum	5.64E-05	0.00E+00	5.78E-04	1.58E-03	3.11E-04
Sum	1.39E-02	0.00E+00	1.63E-01	2.33E-01	1.00E-01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.76E-07	0.00E+00	3.33E-06	1.05E-05	1.93E-06

Table G-38 ADD Inhalation of Ta for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	1.33E-05	4.15E-05	2.17E-05	1.02E-05	1.82E-06	1.27E-05
Standard Error	1.25E-07	7.96E-07	3.61E-07	3.57E-08	7.67E-09	8.60E-08
Median	1.26E-05	3.60E-05	2.13E-05	1.02E-05	1.80E-06	1.23E-05
Standard Deviation	3.95E-06	2.52E-05	1.14E-05	1.13E-06	2.43E-07	2.72E-06
Sample Variance	1.56E-11	6.34E-10	1.30E-10	1.28E-12	5.89E-14	7.40E-12
Kurtosis	1.54E+01	1.12E+02	6.95E-02	8.01E-02	8.00E-01	1.24E+00
Skewness	2.49E+00	7.86E+00	4.37E-01	2.67E-01	5.74E-01	8.49E-01
Range	4.61E-05	4.73E-04	6.38E-05	7.73E-06	1.63E-06	1.84E-05
Minimum	5.27E-06	1.61E-05	5.61E-09	6.81E-06	1.26E-06	6.00E-06
Maximum	5.14E-05	4.89E-04	6.38E-05	1.45E-05	2.89E-06	2.43E-05
Sum	1.33E-02	4.15E-02	2.17E-02	1.02E-02	1.82E-03	1.27E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.45E-07	1.56E-06	7.08E-07		1.51E-08	1.69E-07

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	6.52E-06	2.33E-06	3.20E-06	3.49E-05	1.69E-05
Standard Error	7.14E-08	4.10E-08	2.77E-08	7.09E-07	1.10E-07
Median	6.03E-06	2.08E-06	3.07E-06	3.15E-05	1.64E-05
Standard Deviation	2.26E-06	1.30E-06	8.77E-07	2.24E-05	3.47E-06
Sample Variance	5.10E-12	1.68E-12	7.70E-13	5.03E-10	1.21E-11
Kurtosis	1.58E+01	3.09E+01	3.15E+00	2.81E+00	1.77E+00
Skewness	2.48E+00	4.12E+00	1.18E+00	1.24E+00	9.05E-01
Range	2.75E-05	1.56E-05	7.08E-06	1.65E-04	2.72E-05
Minimum	2.87E-06	2.33E-07	1.36E-06	6.07E-08	8.29E-06
Maximum	3.04E-05	1.58E-05	8.44E-06	1.65E-04	3.55E-05
Sum	6.52E-03	2.33E-03	3.20E-03	3.49E-02	1.69E-02
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.40E-07	8.06E-08	5.44E-08	1.39E-06	2.16E-07

Table G-39 EHQ of Ta for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	2.95E-01	2.90E-01	2.83E-01
Standard Error	5.38E-02	3.40E-02	3.80E-02
Median	1.34E-01	1.36E-01	1.23E-01
Standard Deviation	1.70E+00	1.07E+00	1.20E+00
Sample Variance	2.90E+00	1.15E+00	1.45E+00
Kurtosis	8.79E+02	5.56E+02	6.71E+02
Skewness	2.88E+01	2.14E+01	2.42E+01
Range	5.23E+01	2.95E+01	3.46E+01
Minimum	6.00E-03	4.00E-03	3.00E-03
Maximum	5.23E+01	2.95E+01	3.46E+01
Sum	2.95E+02	2.90E+02	2.83E+02
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.06E-01	6.66E-02	7.46E-02

Table G-40 Cp of Ta for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	7.38E-02	7.26E-02	7.08E-02
Standard Error	1.35E-02	8.49E-03	9.51E-03
Median	3.30E-02	3.40E-02	3.10E-02
Standard Deviation	4.25E-01	2.68E-01	3.01E-01
Sample Variance	1.81E-01	7.21E-02	9.04E-02
Kurtosis	8.79E+02	5.56E+02	6.71E+02
Skewness	2.88E+01	2.14E+01	2.42E+01
Range	1.31E+01	7.37E+00	8.64E+00
Minimum	1.00E-03	1.00E-03	1.00E-03
Maximum	1.31E+01	7.38E+00	8.65E+00
Sum	7.38E+01	7.26E+01	7.08E+01
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.64E-02	1.67E-02	1.87E-02

Table G-41 EHQ of DU for Terrestrial animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	1.00E+00	3.86E+00	2.07E-01	7.05E-02	8.94E-02	1.12E+00
Standard Error	3.31E-02	1.08E-01	4.32E-03	2.62E-03	5.64E-03	3.61E-02
Median	6.33E-01	3.05E+00	1.62E-01	4.69E-02	4.00E-02	7.82E-01
Standard Deviation	1.05E+00	3.41E+00	1.37E-01	8.27E-02	1.78E-01	1.14E+00
Sample Variance	1.09E+00	1.16E+01	1.87E-02	6.84E-03	3.18E-02	1.31E+00
Kurtosis	1.41E+01	1.68E+02	1.02E+01	7.03E+01	1.52E+02	4.07E+01
Skewness	3.20E+00	1.07E+01	2.78E+00	6.33E+00	9.63E+00	4.94E+00
Range	8.63E+00	6.77E+01	1.10E+00	1.33E+00	3.54E+00	1.58E+01
Minimum	1.21E-01	2.18E+00	8.46E-02	8.01E-03	8.63E-04	2.67E-01
Maximum	8.75E+00	6.99E+01	1.18E+00	1.34E+00	3.54E+00	1.60E+01
Sum	1.00E+03	3.86E+03	2.07E+02	7.05E+01	8.94E+01	1.12E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	6.49E-02	2.11E-01	8.48E-03	5.13E-03	1.11E-02	7.09E-02

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	5.87E-01	3.04E-01	1.47E-01	1.40E+00	9.99E-02
Standard Error	2.03E-02	2.09E-02	4.82E-03	5.08E-02	4.37E-03
Median	3.91E-01	1.11E-01	1.04E-01	8.96E-01	6.26E-02
Standard Deviation	6.43E-01	6.61E-01	1.53E-01	1.61E+00	1.38E-01
Sample Variance	4.13E-01	4.37E-01	2.33E-02	2.58E+00	1.91E-02
Kurtosis	3.06E+01	1.24E+02	8.14E+01	4.28E+01	1.41E+02
Skewness	4.50E+00	8.68E+00	7.15E+00	5.09E+00	9.13E+00
Range	7.30E+00	1.24E+01	2.49E+00	2.23E+01	2.70E+00
Minimum	6.83E-02	3.12E-02	6.10E-02	2.49E-01	1.29E-02
Maximum	7.37E+00	1.24E+01	2.55E+00	2.25E+01	2.71E+00
Sum	5.87E+02	3.04E+02	1.47E+02	1.40E+03	9.99E+01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	3.99E-02	4.10E-02	9.47E-03	9.96E-02	8.58E-03

Table G-42 ADD Ingestion of DU for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	2.46E+00	1.28E+01	2.96E+00	1.01E+00	8.04E-02	2.53E+00
Standard Error	8.10E-02	3.58E-01	6.19E-02	3.75E-02	5.07E-03	8.18E-02
Median	1.55E+00	1.01E+01	2.32E+00	6.72E-01	3.60E-02	1.77E+00
Standard Deviation	2.56E+00	1.13E+01	1.96E+00	1.18E+00	1.60E-01	2.59E+00
Sample Variance	6.57E+00	1.28E+02	3.83E+00	1.40E+00	2.57E-02	6.69E+00
Kurtosis	1.41E+01	1.68E+02	1.02E+01	7.02E+01	1.52E+02	4.07E+01
Skewness	3.20E+00	1.07E+01	2.78E+00	6.33E+00	9.63E+00	4.94E+00
Range	2.11E+01	2.25E+02	1.57E+01	1.90E+01	3.19E+00	3.57E+01
Minimum	2.97E-01	7.26E+00	1.21E+00	1.14E-01	7.76E-04	6.04E-01
Maximum	2.14E+01	2.32E+02	1.69E+01	1.91E+01	3.19E+00	3.63E+01
Sum	2.46E+03	1.28E+04	2.96E+03	1.01E+03	8.04E+01	2.53E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.59E-01	7.02E-01	1.21E-01	7.35E-02	9.96E-03	1.60E-01

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	1.14E+00	2.74E-01	1.30E-01	4.36E+00	1.43E+00
Standard Error	3.95E-02	1.88E-02	4.34E-03	1.58E-01	6.26E-02
Median	7.61E-01	9.98E-02	9.07E-02	2.79E+00	8.96E-01
Standard Deviation	1.25E+00	5.95E-01	1.37E-01	5.00E+00	1.98E+00
Sample Variance	1.56E+00	3.54E-01	1.88E-02	2.50E+01	3.92E+00
Kurtosis	3.06E+01	1.24E+02	8.17E+01	4.28E+01	1.41E+02
Skewness	4.50E+00	8.68E+00	7.17E+00	5.09E+00	9.13E+00
Range	1.42E+01	1.11E+01	2.24E+00	6.94E+01	3.86E+01
Minimum	1.33E-01	2.81E-02	5.45E-02	7.68E-01	1.85E-01
Maximum	1.43E+01	1.12E+01	2.29E+00	7.02E+01	3.88E+01
Sum	1.14E+03	2.74E+02	1.30E+02	4.36E+03	1.43E+03
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	7.76E-02	3.69E-02	8.51E-03	3.10E-01	1.23E-01

Table G-43 ADD Dermal Absorption of DU for Terrestrial Animals at YPG

Statistical data	Black-tailed jackrabbit	Lesser long-nosed bat	Loggerhead shrike	Mexican spotted owl	Desert tortoises	Kit fox
Mean	6.39E-04	4.57E-03	2.31E-03	7.53E-04	0.00E+00	5.46E-04
Standard Error	4.25E-05	2.58E-04	1.11E-04	3.66E-05	0.00E+00	2.59E-05
Median	3.06E-04	1.90E-03	1.17E-03	3.59E-04	0.00E+00	2.89E-04
Standard Deviation	1.34E-03	8.16E-03	3.52E-03	1.16E-03	0.00E+00	8.18E-04
Sample Variance	1.80E-06	6.67E-05	1.24E-05	1.34E-06	0.00E+00	6.70E-07
Kurtosis	1.13E+02	2.76E+01	2.62E+01	2.73E+01	#DIV/0!	5.85E+01
Skewness	9.03E+00	4.52E+00	4.30E+00	4.31E+00	#DIV/0!	5.80E+00
Range	2.13E-02	8.52E-02	3.59E-02	1.22E-02	0.00E+00	1.25E-02
Minimum	3.26E-06	4.52E-05	2.35E-05	4.62E-06	0.00E+00	2.54E-06
Maximum	2.13E-02	8.52E-02	3.59E-02	1.22E-02	0.00E+00	1.25E-02
Sum	6.39E-01	4.57E+00	2.31E+00	7.53E-01	0.00E+00	5.46E-01
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	8.33E-05	5.07E-04	2.18E-04	7.18E-05	0.00E+00	5.08E-05

Statistical data	Mule deer	Sonora whipsnake	Desert spiny Lizards	Cactus mouse	Gambel's quail
Mean	2.11E-04	0.00E+00	2.69E-03	3.71E-03	1.51E-03
Standard Error	1.42E-05	0.00E+00	1.59E-04	2.66E-04	9.69E-05
Median	9.42E-05	0.00E+00	1.20E-03	1.35E-03	7.66E-04
Standard Deviation	4.47E-04	0.00E+00	5.04E-03	8.42E-03	3.06E-03
Sample Variance	2.00E-07	0.00E+00	2.54E-05	7.08E-05	9.39E-06
Kurtosis	2.21E+02	#DIV/0!	6.43E+01	8.09E+01	1.77E+02
Skewness	1.17E+01	#DIV/0!	6.63E+00	7.39E+00	1.10E+01
Range	9.83E-03	0.00E+00	6.70E-02	1.33E-01	6.09E-02
Minimum	2.46E-06	0.00E+00	3.58E-05	3.95E-06	8.92E-06
Maximum	9.83E-03	0.00E+00	6.70E-02	1.33E-01	6.09E-02
Sum	2.11E-01	0.00E+00	2.69E+00	3.71E+00	1.51E+00
Count	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.78E-05	0.00E+00	3.13E-04	5.22E-04	1.90E-04

Table G-44 EHQ of DU for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	1.35E+00	1.37E+00	1.47E+00
Standard Error	1.11E-01	9.94E-02	1.54E-01
Median	5.11E-01	5.39E-01	4.95E-01
Standard Deviation	3.51E+00	3.14E+00	4.87E+00
Sample Variance	1.23E+01	9.88E+00	2.37E+01
Kurtosis	2.72E+02	1.39E+02	5.38E+02
Skewness	1.33E+01	9.64E+00	2.05E+01
Range	8.10E+01	5.73E+01	1.33E+02
Minimum	3.00E-03	7.00E-03	5.00E-03
Maximum	8.10E+01	5.73E+01	1.33E+02
Sum	1.35E+03	1.37E+03	1.47E+03
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	2.18E-01	1.95E-01	3.02E-01

Table G-45 Cp of DU for Terrestrial Plants at YPG

Statistical data	CreosoteBush	FoothillPaloverde Tree	SaguaroCactus
Mean	6.74E-01	6.84E-01	7.36E-01
Standard Error	5.55E-02	4.97E-02	7.70E-02
Median	2.56E-01	2.69E-01	2.48E-01
Standard Deviation	1.75E+00	1.57E+00	2.43E+00
Sample Variance	3.08E+00	2.47E+00	5.92E+00
Kurtosis	2.72E+02	1.39E+02	5.38E+02
Skewness	1.33E+01	9.64E+00	2.05E+01
Range	4.05E+01	2.86E+01	6.65E+01
Minimum	1.00E-03	4.00E-03	3.00E-03
Maximum	4.05E+01	2.87E+01	6.65E+01
Sum	6.74E+02	6.84E+02	7.36E+02
Count	1.00E+03	1.00E+03	1.00E+03
Confidence Level (95.0%)	1.09E-01	9.75E-02	1.51E-01

APPENDIX H

SOLUBILITY ESTIMATION EQUATIONS

Regression Equation for the Estimation of S (Lyman *et al*, 1990)

Eq.No	Equation[a]	Units of S	No.[b]	r^{2c}	Chemical Classess Represented
1	$\log S = -1.37\log K_{ow} + 7.26$	μmol/L	41	0.903	Mixed classes; aromatics and chlorinated hydrocarbons well represented
2	$\log S = -0.922\log K_{ow} + 4.184$	mg/L	90	0.740	Mixed classes; pesticides well represented
3	$\log S = -1.49\log K_{ow} + 7.46$	μmol/L	34	0.970	Mixed classes; several pesticides
4	$\log 1/S = 1.113\log K_{ow} - 0.926$	mol/L[d]	41	0.935	Alcohols[e]
5	$\log 1/S = 1.229\log K_{ow} - 0.720$	mol/L[d]	13	0.960	Ketones[e]
6	$\log 1/S = 1.013\log K_{ow} - 0.520$	mol/L[d]	18	0.980	Esters[e]
7	$\log 1/S = 1.182\log K_{ow} - 0.935$	mol/L[d]	12	0.880	Ethers[e]
8	$\log 1/S = 1.221\log K_{ow} - 0.832$	mol/L[d]	20	0.861	Alkyl halides[e]
9	$\log 1/S = 1.294\log K_{ow} - 1.043$	mol/L[d]	7	0.908	Alkynes[e]
10	$\log 1/S = 1.294\log K_{ow} - 0.248$	mol/L[d]	12	0.970	Alkenes[e]
11	$\log 1/S = 0.996\log K_{ow} - 0.339$	mol/L[d]	16	0.951	Aromatics[e](benzene and benzene derivatives)
12	$\log 1/S = 1.237\log K_{ow} + 0.248$	mol/L[d]	16	0.908	Alkanes[e]
13	$\log 1/S = 1.214\log K_{ow} - 0.850$	mol/L[d]	140	0.912	All chemical represented by Eqs. 4-12 plus propionitrile[e]
14	$\log 1/S = 1.339\log K_{ow} - 0.978$	mol/L[d]	156	0.874	All chemicals represented by Eqs.4-12 plus propionitrile[e]
15	$\log S = -2.38\log K_{ow} + 12.90$	μmol/L	11	0.656	Phosphate esters
16[f]	$\log S = -0.9874\log K_{ow} - 0.0095t_m + 0.77178$	mol/L	35	0.990	Halobenzenes
17[f]	$\log S = -0.88\log K_{ow} - 0.01t_m - 0.012$	mol/L	32	0.979	Rigid aromatic hydrocarbons (polynuclear aromatics)
18	$\log S = -0.962\log K_{ow} + 6.50$	μmol/L	9	0.878	Halogenated 1- and 2-carbon hydrocarbon (8 with Cl, 1 with Br)

a. S = aqueous solubility; K_{0w} = octanol/water partition coefficient; t_m = melting point (^{0}C), $t_m \geq 25^0$C; N = number of carbon atoms in molecule.

b. No. = number of compounds in data set used to obtain equation.

c. r^2 = square of correlation coefficient

d. Actually, moles/ 1000 g of water (i.e., molar solubility). For most chemicals this is very close to the molar solubility (moles/liter of solution), and no correction need be applied.

e. All chemicals used were liquids. Values of K_{ow} for many of these chemicals were estimated.

f. If t_m is less than 25^{0}C, a value of 25^{0}C should be used for t_m in Eqs.16-17.

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