COMPARTMENT-BASED WETLAND ECOSYSTEM CONTAMINANT TRANSFER MODEL FOR ASSESSING ECOSYSTEM RISK

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Submitted to the Faculty of the
Graduate College of
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2000

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ACKNOWLEDGEMENTS

I first wish to give thanks and glory to my Lord and Savior Jesus Christ, without whom my life and any personal accomplishments would be meaningless and hollow. I also thank my major advisor, Dr. William McTernan, for his guidance, support, encouragement, and unwavering belief in my abilities. Dr. McTernan's constant challenges resulted in me a level of intellectual and professional maturation which I did not expect to gain from graduate school.

I thank my family for their support. I could not have realized many of my ambitions if not for the love, support, and personal sacrifices of my parents. My wife, Lisa, also deserves a sincere thank you. Lisa's complete selfless love has been one of the few constants in my life over the past several years. To the countless other family members and friends who have provided their support and encouragement, I thank them all.

Lastly, I would like to thank my employer, Fibercast Company, who provided much of the financial support for my graduate education.

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1. INTRODUCTION

Degradation of the natural environment due to human activity has been well documented in American literature by the likes of Aldo Leopold in *Sand County Almanac* (1949) and Rachel Carson's *Silent Spring* (1962). However, it was not until the 1970's when widespread human health was imminently threatened that the U.S. Environmental Protection Agency (EPA) was created by an Executive Order. A series of Federal environmental regulations that became increasingly popular with the American public were subsequently promulgated. The EPA, along with its state analogues and other governmental agencies, is primarily charged with determining to what extent environmental releases of contaminants will result in a minimal negative impact on the general population. In other words, "What level of risk is acceptable to society?" This is not a simple task.

More often than not, it seems that determining what is an acceptable level of risk is based not so much on science, but rather on political agendas, industrial propaganda, and grass roots ideologies. Unfortunately, groups on all sides of an environmental debate can often produce "scientific evidence" to support their particular views. The reason for this is largely due to the complexity of the human physiology coupled with the myriad of chemicals which must be regulated. Adding to the dilemma is a scientific lack of understanding surrounding many of these chemicals. Even more confounding to the problem is that many environmental contaminants may exist in several different forms once released into the environment, either through natural attenuation or by reacting with elements already present. This only serves to increase the level of uncertainty in the regulatory arena of human health and associated decision-making processes.

The subject of this work is ecological risk assessment. For all of the uncertainties that may exist in determining an acceptable level of risk to allow in human health assessments, broadening the application to the complexity of an ecosystem-level analysis greatly widens the chasm between what is known and what must be derived by mathematical interpolation (i.e., modeling).

Environmental contamination may adversely affect human health and/or ecosystem viability. As environmental contamination often results from routine economic activities, management approaches are needed to define contaminant release levels that afford protection to humans and the receiving ecosystems. Often these levels can be adequately described and attained by a specific numeric standard. More frequently however, complexities associated with either propagation of disease in humans or in environmental degradation within ecosystems serves to minimize the effectiveness of a standard. Risk assessment approaches have been developed to address more complex situations.

In a broad classification, risk assessments have traditionally focussed on human health considerations (*environmental risk assessment*) or ecosystem concerns (*ecological risk assessment*). Ecological risk assessment requires an effective method of assigning and attaining regulatory and societal goals at a reasonable cost and within an acceptable timeframe. Due to the massive variability and complexity inherent in ecosystems, this is only possible through a logical breakdown of responsibilities performed by a multidisciplinary team.

The term *ecological risk assessment* is defined below. Several simulation models will be reviewed as well as some of the techniques which attempt to deal with the uncertainty surrounding model inputs and outputs. The focus here is the application of a risk assessment model to a wetland ecosystem. The term wetland will be defined and the importance of wetland ecosystems will be discussed. Lastly, recent status and trends of wetlands in North America will be described.

1.1 Ecological Risk Assessment - Defined

An ecological risk assessment can be defined as the process of scientifically evaluating the probability (or likelihood) of compromising ecological integrity due to exposure to stressors (or contaminants) related to human activities (Norton *et al.* 1992). Furthermore, the assessment process should also give some measure of the magnitude of the compromising effects (Matlock *et al.* 1994). Norton *et al.* (1992) defined stressors as any chemical, physical, or biological entity that can elicit harmful ecological effects. Thus, the ecological risk assessment process must be broad enough to encompass the variety found in any given ecosystem. Due to the inherent complexities and lack of understanding of many ecological processes, no ecological risk assessment will ever be perfect or totally complete (Cairns and McCormick 1992). However, there are guidelines in place that, if followed, should give as complete an assessment as possible.

The purpose of this work is not to provide a treatise on ecological risk assessment, but rather to develop and describe a mathematical model which may be used as a tool by risk assessors along with a discussion of the methods for understanding and managing inherent uncertainties. Modeling ecological risk is only part of the overall risk assessment process. Several protocols have been developed for completing an ecological risk assessment. The particular protocol chosen may depend upon several factors including: (1) statutory requirements, (2) site-, contaminant-, or species-specific applicability, (3) time limits/requirements, and (4) ultimate goals. Norton *et al.* (1992), Cairns and McCormick (1992), and Hope (1995), provide in-depth discussions of three ecological risk paradigms. A brief description of these paradigms is provided below. Although not intended to be inclusive of the whole of ecological risk assessment philosophies, these three methodologies illustrate the variety of the field.

The EPA's ecological risk assessment paradigm, as described by Norton *et al.* (1992), is a *tri-phase* process consisting of (1) Problem Formulation, (2) Analysis, and (3) Risk Characterization. In the formulation phase, the specific stressor of concern is identified and a conceptual model created or chosen to explain the ecological interactions. The analysis phase uses the site-specific or site-appropriate model to evaluate collected information and stressor-related ecological impacts. Risk characterization estimates the potential ecological risks and evaluates potential remedial technologies.

Hope (1995) described an ecological risk paradigm similar to that of the EPA's but broke the process down into seven phases in an attempt to better define goals, optimize time, increase overall quality, and more efficiently allocate costs. Each of Hope's (1995) phases, which he called *work breakdown structures* (WBS's), were further divided into several sub-phases. Hope (1995) stated that it is extremely important to maintain an orderly and structured approach to ecological risk assessment in order to keep projects within budget and on schedule.

Cairns and McCormick (1992) offer a slightly different philosophy towards ecological risk assessment than those described by Norton *et al.* (1992) and Hope (1995). Rather than emphasizing laboratory experimentation and conceptual modeling, Cairns and McCormick (1992) suggest ongoing biological monitoring of carefully selected indicators of ecological integrity. As Cairns and McCormick (1992) point out, since "everything is an indicator of something, but nothing is an indicator of everything" selection of the appropriate indicator species is paramount to the successful discharge of their protocol.

1.2 Modeling Ecological Risk

Both Norton *et al.* (1992) and Hope (1995) state the need for a conceptual model that relates stressor-receptor interactions. Even Cairns and McCormick

(1992), who warn against the shortfalls and many uncertainties associated with describing complex ecological processes in the relatively simple format of simulation models, concede their importance. Ideally, ecological risk assessment models should be generic enough to predict the likelihood of many different types of stressors causing adverse effects in various regions to many different types of species (Hanratty and Stay 1994). These models aid the assessment team by estimating stressor exposure to receptors and stressor concentrations in particular media (MacIntosh *et al.* 1993). The models available to risk assessors range from simple bioconcentration models to much more complex food web models which require numerous inputs and extensive laboratory and field investigations. The key is understanding that simulation models are merely tools and that the risk assessor is charged with identifying the correct tool needed to achieve identified goals and objectives.

Aquatic ecological risk assessments have historically relied on steady-state and equilibrium partitioning models (Landrum *et al.* 1992). However, as Landrum *et al.* (1992) argue, simulation of non-steady-state and non-equilibrium phenomena in proper temporal and spatial context requires the use of kinetic models. Kinetic models are better able to simulate stressor concentrations in receptor tissues due to absorption, distribution, metabolism, and elimination (Landrum *et al.* 1992). Landrum *et al.* (1992) and MacIntosh *et al.* (1993) provide an overview of many of the previously mentioned models. A few of those are examined here.

1.2.1 Steady-State Models

Receptors are said to be at steady-state when stressor exposure and uptake and loss factors remain unchanged. This equilibrium state may be assumed for resident receptors with relatively long life-cycles (MacIntosh *et al.* 1993). For aquatic stressor exposures under these conditions, a tissue bioconcentration factor (BCF) in milliliters per gram can be expressed as:

$$\mathrm{BCF} = \frac{C_a}{C_w} \tag{1}$$

where:

C_a = stressor concentration in the receptor (μg/g)

C_w = stressor concentration in the water (μg/mL)

When assessing risk to benthic receptors the above equation can be modified to focus on stressor uptake from sediment or food source to yield a bioaccumulation factor (BAF) in grams of sediment or food source per gram of tissue:

$$\mathrm{BAF} = \frac{C_a}{C_s} \tag{2}$$

where:

C_s = stressor concentration in the sediment or food source (μg/g)

The last steady-state model given by Landrum *et al.* (1992) again describes stressor uptake from sediment or food source. However, it also takes into account the lipid content in the stressor and organic carbon content in the foodstuff. This accumulation factor (AF) in grams of organic carbon per grams of lipid is:

$$AF = \frac{C_a(l)}{C_s(c)} \tag{3}$$

where:

$C_a(l)$ = receptor stressor concentration per gram lipid (µg/g)

$C_s(c)$ = source stressor concentration per gram organic carbon (µg/g)

1.2.2 Kinetic Models

Landrum *et al.* (1992) state that kinetic models can be placed into one of two categories: (1) compartment-based or (2) physiology-based. Compartment-based models describe stressor movement between the biotic components, or compartments (e.g., species, population, trophic level), and the abiotic components (i.e., water, soil, sediment) of an ecosystem system. Physiology-based pharmacokinetic (PBPK) models simulate stressor accumulation and distribution within receptor tissues.

1.2.3 Compartment Models

Landrum *et al.* (1992) detail many of the assumptions associated with compartment models: (1) homogeneous mixture of stressor within each compartment, (2) no stressor biotransformation, (3) rate constants do not change over time, and (4) first-order transfer between compartments.

Using first-order transfer functions, with the stressor concentration in the water compartment (C_w) held static, Landrum *et al.* (1992) provide the following model for calculation of the stressor concentration in the receptor (C_a):

$$C_a = \left(\frac{k_u \cdot C_w}{k_e}\right)\left(1 - e^{-k_e t}\right) \tag{4}$$

where:

k_u = conditional uptake clearance (mg/g/hour)

k_e = conditional elimination rate constant (hour^{-1})

t = time (hours)

The term clearance is defined as the mass of a compartment relieved of stressor per mass of receptor per time (Landrum *et al.* 1992).

Growth compensation can be applied to the above model by adding a first-order growth rate constant in grams per gram per hour (g) to the elimination rate constant (k_e):

$$C_a = \left(\frac{k_u \cdot C_w}{k_e + g}\right)\left(1 - e^{-(k_e + g)t}\right) \tag{5}$$

Decay could similarly be incorporated into the model by applying the term as a negative value.

MacIntosh *et al.* (1993) described a compartment-based model similar to equations 3 and 4 which gave a bioaccumulation factor for the stressor from contaminated food:

$$BAF = (BCF + BMF)\left(1 - e^{k_{el} t}\right) \tag{6}$$

where:

BCF = bioconcentration factor: stressor partitioning between compartments

(mL/g)

BMF = biomagnification factor: stressor uptake from contaminated food (unitless)

k_{el} = conditional elimination rate constant (day^{-1})

t = average receptor life span (days)

To calculate stressor uptake (BMF) from food and drinking water, MacIntosh *et al.* (1993) employed the following equation:

$$BMF = M \cdot \sum f \cdot BAF + I_w \cdot A_{eff} \cdot k_{el}^{-1} \tag{7}$$

with,

$$M = I_p \cdot A_{eff} \cdot k_{el}^{-1} \tag{8}$$

where:

M = magnification term (unitless)

f = fraction of predator diet consisting of prey (unitless)

I_p = amount of food ingested (g/g/day)

I_w = amount of water ingested (g/g/day)

BAF = bioaccumulation factor for each prey (unitless)

A_{eff} = fraction of ingested stressor that is absorbed across the gut lining of the receptor (unitless)

In small static systems stressor concentration in the water compartment decreases as it is accumulated in the receptor. By incorporating the mass balance of stressor in each compartment, Landrum *et al.* (1992) state that the concentration of the stressor in the receptor (Q_a) can be expressed as:

$$Q_a = \frac{(k_{um} \cdot A)\left(1 - e^{-(k_{um}+k_e)t}\right)}{k_{um} + k_e} \tag{9}$$

where:

A = stressor in the system ($Q_w + Q_a$) in μg

k_{um} = uptake rate constant (hour^{-1})

1.2.4 Physiology-Based Pharmacokinetic Models

Physiology-based pharmacokinetic (PBPK) models compartmentalize the receptor into related tissue types (Landrum *et al.* 1992). PBPK models are attractive due to the fact that they can be used on practically any species given the availability of that species' physiological information. However, these models also require much more prior information for proper implementation than do the aforementioned compartment models (Landrum *et al.* 1992).

1.3 Model Selection

The assessor should take great care in choosing the proper model which will be used to describe a study site. If the initial phases of the risk assessment are performed properly (i.e., within a logical framework and with clear goals in mind), choosing the correct simulation model will be a much easier task. Once the proper model or suite of models is chosen, the risk assessor must then make a decision on how to deal with the uncertainty associated with his choice.

1.4 Uncertainty Analysis

Simulation models used in ecological risk assessment are often plagued with a large amount of uncertainty surrounding their input and output values. These uncertainties can come from a variety of sources, such as: limited understanding of ecological processes, limited access or ability to measure actual ranges of model inputs and parameters, sampling error, ecological variability, and mathematical oversimplification of ecological processes (Dakins *et al.* 1995). If ignored, these uncertainties can compromise the utility of a model and thus lead to poor or improper decision making. A widely used method to combat the uncertainty found in parameter selection for simulation modeling is Monte Carlo analysis.

1.4.1 Monte Carlo Analysis

Monte Carlo analysis samples statistical frequency distributions (a.k.a. probability distribution functions) for uncertain model parameters. These probability distribution functions (pdfs) are calculated from value ranges obtained from published or field data. Simulations are run numerous times, randomly accessing values for each iteration from the user-defined distributions (Dilks *et al.* 1992). Monte Carlo analysis is attractive to modelers due to its applicability to many different types of models as well as to many types of frequency distributions (i.e., normal, log-normal, triangular, etc.) (Slob 1994). Figure 1 clearly shows the difference between a typical deterministic (point) estimate and a Monte Carlo (probabilistic or stochastic) estimate using distribution functions rather than single average values for each input parameter.

The point estimate shown at the top of Figure 1 depicts four values (A, B, C, and D) which are used to calculate the result (E). In a traditional analysis, the four values would likely represent averages of several actual field or laboratory measurements. The result (E) then represents a rather sterile average answer which does not enlighten the researcher to the variability common in natural systems. The graphic in the lower half of Figure 1 depicts the same four input variables, however, rather than only using single average values, the Monte Carlo approach utilizes density functions developed from measurements. In this way, the analyst can define probabilities of occurrence for the outputs.

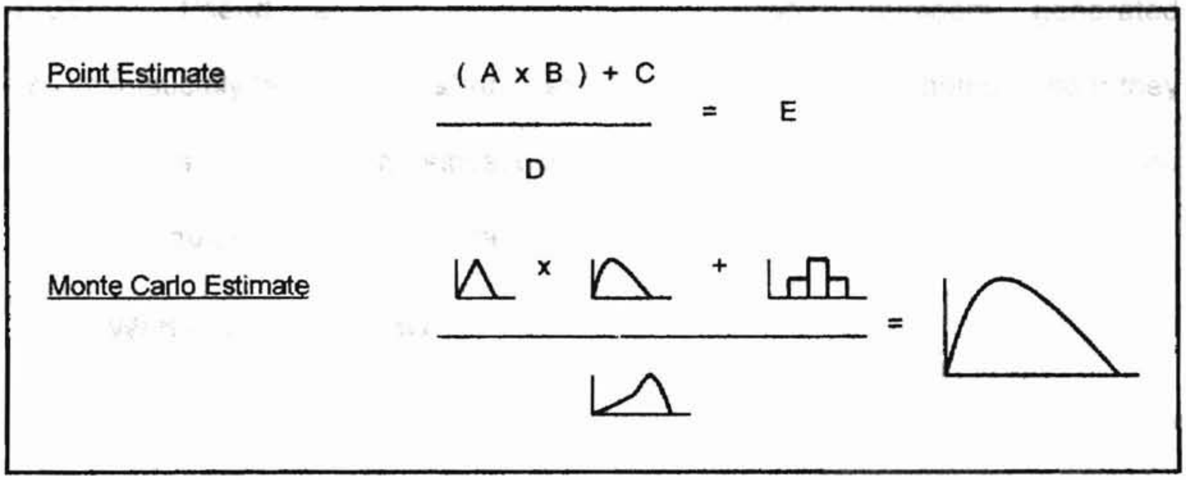


Figure 1. Comparison of a point estimate and a Monte Carlo estimate.

1.4.2 Latin Hypercube

Latin Hypercube is a stratification of the pdfs which "allows the output distribution to be characterized with a smaller number of replications than simple random sampling" (Dakins *et al.* 1995, pg. 69). Once the pdf is stratified, or separated into equal intervals, samples are randomly taken from each interval (Palisade 1996). Each stratification is sampled only once during an analysis. In this manner, Latin Hypercube analysis reportedly more accurately represents the input pdf with fewer iterations than with a traditional Monte Carlo analysis (Palisade 1996).

1.4.3 Statistical Quality of Monte Carlo Analysis

The statistical quality of a Monte Carlo analysis is dependent upon the quality of the uniform random number generator employed by the particular software used. Unbeknownst to many analysts is the fact that computers use "mechanical, wholly deterministic methods" to generate random numbers (Barry 1995). Pseudo-random numbers (i.e., random numbers generated deterministically by computers) are defined by Barry (1995) as being good if they exhibit statistical uniformity, statistical independence, reproducibility, and can be generated quickly and economically.

1.5 Wetland Ecosystems

Wetlands are ecosystems where saturation with water is the dominant factor determining the types of plant and animal communities living in the soil or on its surface (i.e., habitat which is transitional between terrestrial and aquatic systems in which the water table usually lies at or near the surface.) (Cowardian *et al.* 1979). Wetlands provide critical feeding, resting, and breeding habitat for many waterfowl, shorebirds, and Neotropical migrants as well as many other animals (Hobbs and Barksdale 1993). Wetlands are also very important to humans by reducing flooding problems through temporary storage of flood waters. Wetlands aid water quality by filtering out pollutants and sediments, and also provide recreation (*e.g.,* hunting, bird watching) (USDI 1988).

1.5.1 Status of Wetlands in North America

Of the approximately 87 million-ha of wetlands that existed in North America at the time of the continent's settlement, only about 41 million-ha remained in the 1980's (Frayer 1991). These figures equate to an approximate 53% net loss of the nation's wetlands.

2. METHODOLOGY

The model chosen for this wetland ecosystem risk assessment is an adaptation of the classic *carrying capacity* equation which has seen widespread use among wildlife management professionals. This model was chosen because it incorporates many of the characteristics of the equations previously described from Landrum *et al.* (1992) and MacIntosh *et al.* (1993) such as first-order kinetics and steady-state equilibrium partitioning. Further, the model lends itself to a compartment-based application. The basic carrying capacity equation, as taken from Anderson (1991), is as follows:

$$\frac{dN}{dt} = rN\left(\frac{K-N}{K}\right) \tag{10}$$

where:

r = constant, *intrinsic rate of increase*, equal to the birth rate minus the death rate

N = number of individuals in the population at a given moment

K = *carrying capacity*, the maximum number of individuals a habitat can support

t = time

The carrying capacity model provides wildlife professionals with a useful tool for managing animals in a population context. The equation simulates three basic phenomena of population growth: (1) exponential growth, typical of small populations increasing rapidly in an under-utilized habitat; (2) logarithmic growth, typical of relatively larger populations in which growth is slowed due to decreasing availability of resources; and (3) population stabilization, in which the population growth is in equilibrium with the environment (see Figure 2).

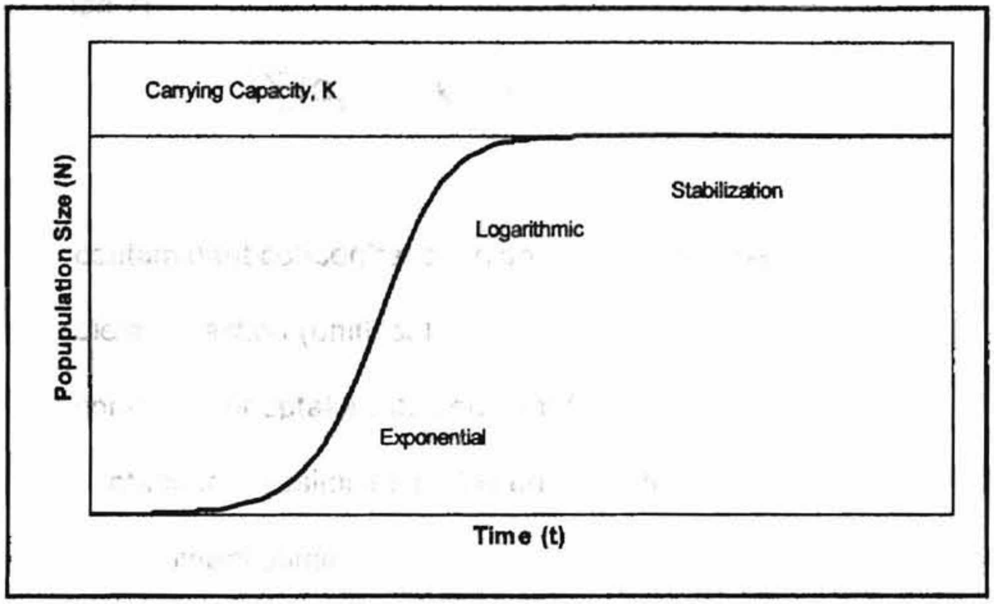


Figure 2. Visual representation of the carrying capacity equation.

2.1 Compartment Model for Assessing Ecological Risk in a Wetland

The model utilized for this work has the same basic form as the carrying capacity equation.

$$\frac{dC}{dt} = rC\left(\frac{C_e - C}{C_e}\right) \tag{11}$$

where:

r = net contaminant uptake rate (time^{-1})

C = compartmental contaminant concentration (mg/kg or L)

C_e = endpoint contaminant concentration (mg/kg)

t = time

Further, net contaminant uptake rate, r, is represented by the following expression and is similar to the BMF term employed by MacIntosh *et al.* (1993) (see equation 7):

$$\left[\sum(C_s \cdot df)\cdot(k_u \cdot eff)\right] - k_e \qquad (12)$$

where:

C_s = contaminant concentration in source compartment (mg/kg or L)

df = dietary fraction (unitless)

k_u = contaminant uptake rate constant (kg or L/mg/time)

eff = contaminant assimilation efficiency (unitless)

k_e = contaminant elimination rate constant ($time^{-1}$)

Therefore, the compartmental contaminant concentration can be calculated for C_t as follows:

$$C_t = \left(\left[\left(\left[\sum(C_s \cdot df)\cdot(k_u \cdot eff)\right] - k_e\right)\cdot C_{t-1}\right]\cdot\left[\frac{C_e - C_{t-1}}{C_e}\right]\right) + C_{t-1} \qquad (13)$$

The model above provides an estimate of risk, the *Risk Factor* (RF), based on the ratio of the contaminant concentration within a compartment and the user-defined endpoint concentration (C_e) for that compartment. The risk present at a specific time interval or at the maximum contaminant concentration level for a compartment is calculated as follows:

$$RF_t = \frac{C_t}{C_e} \tag{14}$$

and

$$RF_{max} = \frac{C_{max}}{C_e} \tag{15}$$

where:

RF_t = risk factor at time t (unitless)

RF_{max} = risk factor at maximum contaminant concentration level (unitless)

C_t = contaminant concentration at time t (mg/kg)

C_{max} = maximum contaminant concentration (mg/kg)

C_e = endpoint contaminant concentration (mg/kg)

The risk factor is expressed as a unitless number between zero and one. The greater the RF, the greater the risk.

2.2 Explanation of Model Terms

The model requires the user to input several variables. Based on these user-defined inputs, the model will calculate output data. The nomenclature used within the model to identify these variables is described below.

Contaminant Concentration (C). Represents the stressor concentration within a compartment of interest at a particular time. Dependent upon the compartment, the contaminant concentration contains units of mg/kg or mg/L. This term can be expressed in several different forms: C_o, initial contaminant concentration; C_t, contaminant concentration at a specific time interval; C_{max}, maximum contaminant concentration over a user-defined time period; C_e, endpoint concentration; C_s, contaminant concentration in the source compartment.

Endpoint Concentration (C_e). Mathematically, this term sets the asymptotic maximum value which the model will return for a particular compartmental contaminant concentration. For risk assessment purposes, this term is used to identify the concentration at which individuals or components within a compartment of interest may be expected to show signs of overexposure (e.g., infertility, birth defects, mutations, death, etc.). C_e may also be used to represent the concentration at which humans may exhibit ill-effects via exposure to the individuals or components within the contaminated compartments.

Contaminant Concentration in the Source Compartment (C_s). In order for the model to calculate a compartmental contaminant concentration, all source compartments must be identified and "loaded" with an initial contaminant concentration (C_o).

Dietary Fraction (df). Once all relevant inter-compartmental relationships were identified, the fraction of each source compartment utilized by the receiving compartment was estimated. For example, a herbivorous invertebrate compartment could be identified to potentially receive contaminant from terrestrial plants, soil, and water compartments. In this scenario, the model would require the user to define what fraction of each of these compartments the herbivorous invertebrates utilize in their diet. These unitless values must be input as decimals and their sum should equal 1.00.

Contaminant Uptake Rate Constant (k_u). This is the gross contaminant uptake rate for a compartment expressed as either kg/mg/time or L/mg/time.

Contaminant Assimilation Efficiency (eff). This is the fraction of the contaminant which is actually absorbed into the tissues of the individuals comprising a compartment.

Contaminant Elimination Rate Constant (k_e). This is the rate per time at which contaminant is purged from the tissues of the individuals comprising a compartment.

Net Contaminant Uptake Rate (r). Calculated from equation 12, the net contaminant uptake rate represents the relative per time increase, or decrease, of contaminant which persists within each compartment.

Risk Factor (RF). The amount of risk present within each compartment is calculated from equations 14 and 15. RF_t (equation 14) allows the user to estimate the incremental risk present within a given compartment at any point between C_o and C_{max}. RF_{max} (equation 15), the maximum risk factor, calculates the amount of risk present within a compartment at the maximum contaminant concentration encountered over the user-defined time interval. The risk factor is a unitless value between 0 and 1.00. with risk increasing as the RF approaches unity.

2.3 Generalized Wetland Ecosystem Food Web Matrix

The previously described model was applied to a wetland food web matrix consisting of fifteen compartments, twelve biotic and three abiotic. Each of the biotic compartments represents an entire trophic level (e.g., top predator, waterfowl, aquatic plants) rather than populations (e.g., Canada geese, river elms) or individuals. The three abiotic compartments include soil, sediment, and water. The contaminant transfer relationships between the fifteen compartments are provided below as Figure 3.

1. Top Carnivore (TC)
2. Waterfowl (WF)
3. Carnivorous Mammals (CM)
4. Herbivorous Mammals (HM)
5. Terrestrial Carnivorous Invertebrates (TCI)
6. Terrestrial Herbivorous Invertebrates (THI)
7. Terrestrial Plants (TP)
8. Carnivorous Fish (CF)
9. Herbivorous Fish (HF)
10. Aquatic Carnivorous Invertebrates (ACI)
11. Aquatic Herbivorous Invertebrates (AHI)
12. Aquatic Plants (AP)

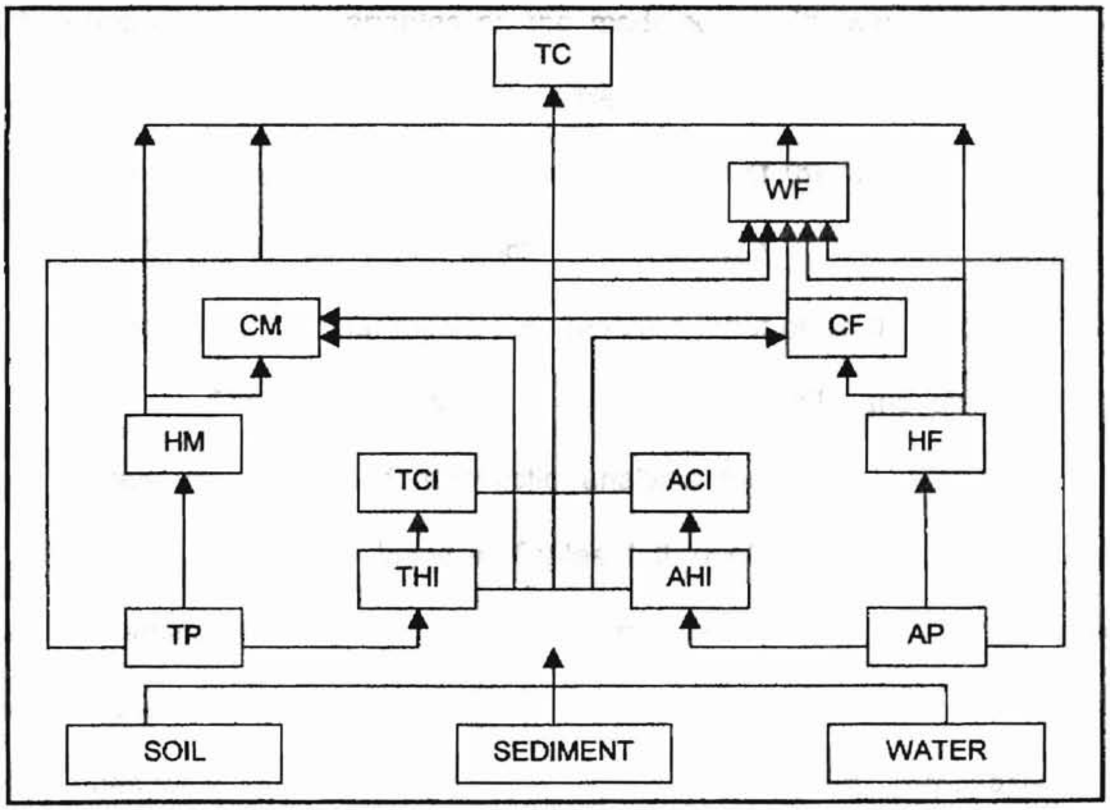


Figure 3. Generalized wetland ecosystem food web matrix.

2.4 Model Input Data

Initial stressor concentration values were adapted from selenium data from Kesterson Reservoir, California (CH2M Hill 1986 and USBR 1990). Site-specific and contaminant-specific data for the remaining input variables (i.e., endpoint concentrations, uptake and elimination rates, assimilation efficiencies, and dietary fractions) were not included in the original reports. Therefore, statistical distributions describing uptake and elimination rates for contaminants other than selenium were adapted from Stehly *et al.* (1990), similar to the approaches of Connoly and Tonelli (1985) and MacIntosh *et al.* (1993). The remaining input variables were estimated from available sources. Subsequently, a sensitivity analysis was performed to determine the applicability of this effort where the relative impact of input variables on the modeled results was evaluated. As discussed later, these uncertain variables were shown to have a negligible effect on the final model output in the sensitivity portion of the stochastic analysis, thereby reinforcing the utility of the technique employed.

The three abiotic compartments only required input of an initial contaminant concentration. The model was run both deterministically and stochastically. Input values used in the deterministic analysis for each compartment and compartment variables are listed in Tables 1 through 14. Table 1 shows the initial contaminant concentration, $C_{o,}$ deterministic input values for variables common to all biotic compartments. Tables 3 through 14 show the deterministic input values for variables specific to each biotic compartment. Stochastic input value ranges are provided in Tables 15 through 31.

Table 1. Initial Se Contaminant Concentration, C_o, Deterministic Input Values for Abiotic Compartments

COMPARTMENT NAME	UNITS	INPUT VALUE [1]
Soil	mg/kg	7.00
Sediment	mg/kg	7.00
Water	mg/L	0.23

[1] CH2M Hill (1986)

Table 2. Deterministic Input Values for Variables Common to all Biotic Compartments

COMPARTMENT NAME	INPUT VALUE				
	C_o	C_e [4]	k_u [3]	k_e [3]	eff [4]
	mg/kg	mg/kg	(kg or L) / mg/time	time^{-1}	unitless
Top Carnivore, TC	9.40 [1]	100.00	0.04	0.02	0.40
Carnivorous Mammals, CM	9.40 [1]	100.00	0.04	0.02	0.35
Herbivorous Mammals, HM	9.40 [1]	100.00	0.05	0.02	0.30
Terrestrial Carnivorous Invertebrates, TCI	10.20 [2]	100.00	0.02	0.01	0.20
Terrestrial Herbivorous Invertebrates, THI	7.80 [2]	100.00	0.05	0.02	0.20
Terrestrial Plants, TP	5.00 [1]	100.00	0.06	0.02	0.40
Waterfowl, WF	4.60 [1]	100.00	0.04	0.02	0.35
Carnivorous Fish, CF	135.00 [1]	250.00	0.04	0.02	0.30
Herbivorous Fish, HF	135.00 [1]	250.00	0.08	0.02	0.30
Aquatic Carnivorous Invertebrates, ACI	114.50 [2]	250.00	0.04	0.02	0.60
Aquatic Herbivorous Invertebrates, AHI	114.50 [2]	350.00	0.08	0.02	0.20
Aquatic Plants, AP	5.00 [1]	100.00	0.10	0.02	0.40

[1] CH2M Hill (1986)
[2] USBR (1990)
[3] Adapted from Stehly (1990)
[4] Estimated

Table 3. Deterministic Input Values for Variables Specific to Top Carnivore Compartment

TOP CARNIVORE SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.10
Sediment	0.05
Water	0.05
Carnivorous Mammals, CM	0.05
Herbivorous Mammals, HM	.030
Terrestrial Carnivorous Invertebrates, TCI	0.10
Terrestrial Herbivorous Invertebrates, THI	0.10
Waterfowl, WF	0.05
Carnivorous Fish, CF	0.05
Herbivorous Fish, HF	0.05
Aquatic Carnivorous Invertebrates, ACI	0.05
Aquatic Herbivorous Invertebrates, AHI	0.05

[1] **Estimated**

Table 4. Deterministic Input Values for Variables Specific to Carnivorous Mammals Compartment

CARNIVOROUS MAMMALS SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.10
Herbivorous Mammals, HM	0.35
Terrestrial Carnivorous Invertebrates, TCI	0.10
Terrestrial Herbivorous Invertebrates, THI	0.10
Waterfowl, WF	0.05
Carnivorous Fish, CF	0.05
Herbivorous Fish, HF	0.05
Aquatic Carnivorous Invertebrates, ACI	0.05
Aquatic Herbivorous Invertebrates, AHI	0.05

[1] **Estimated**

Table 5. Deterministic Input Values for Variables Specific to Herbivorous Mammals Compartment

HERBIVOROUS MAMMALS SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.10
Terrestrial Plants, TP	0.70
Aquatic Plants, AP	0.10

[1] Estimated

Table 6. Deterministic Input Values for Variables Specific to Terrestrial Carnivorous Invertebrates Compartment

TERRESTRIAL CARNIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.20
Sediment	0.05
Water	0.05
Terrestrial Herbivorous Invertebrates, THI	0.60
Aquatic Carnivorous Invertebrates, ACI	0.05
Aquatic Herbivorous Invertebrates, AHI	0.05

[1] Estimated

Table 7. Deterministic Input Values for Variables Specific to Terrestrial Herbivorous Invertebrates Compartment

TERRESTRIAL HERBIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.10
Sediment	0.10
Water	0.05
Terrestrial Plants, TP	0.70
Aquatic Plants, AP	0.05

[1] Estimated

Table 8. Deterministic Input Values for Variables Specific to Terrestrial Plants Compartment

TERRESTRIAL PLANTS SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.75
Sediment	0.05
Water	0.20

[1] Estimated

Table 9. Deterministic Input Values for Variables Specific to Waterfowl Compartment

WATERFOWL SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.20
Terrestrial Carnivorous Invertebrates, TCI	0.05
Terrestrial Herbivorous Invertebrates, THI	0.05
Terrestrial Plants, TP	0.10
Carnivorous Fish, CF	0.10
Herbivorous Fish, HF	0.10
Aquatic Carnivorous Invertebrates, ACI	0.10
Aquatic Herbivorous Invertebrates, AHI	0.10
Aquatic Plants, AP	0.10

[1] Estimated

Table 10. Deterministic Input Values for Variables Specific to Carnivorous Fish Compartment

CARNIVOROUS FISH SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.20
Terrestrial Carnivorous Invertebrates, TCI	0.05
Terrestrial Herbivorous Invertebrates, THI	0.05
Herbivorous Fish, HF	0.50
Aquatic Carnivorous Invertebrates, ACI	0.05
Aquatic Herbivorous Invertebrates, AHI	0.05

[1] Estimated

Table 11. Deterministic Input Values for Variables Specific to Herbivorous Fish Compartment

HERBIVOROUS FISH SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.20
Aquatic Plants, AP	0.70

[1] Estimated

Table 12. Deterministic Input Values for Variables Specific to Aquatic Carnivorous Invertebrates Compartment

AQUATIC CARNIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.20
Terrestrial Carnivorous Invertebrates, TCI	0.05
Terrestrial Herbivorous Invertebrates, THI	0.05
Aquatic Herbivorous Invertebrates, AHI	0.60

[1] Estimated

Table 13. Deterministic Input Values for Variables Specific to Aquatic Herbivorous Invertebrates Compartment

AQUATIC HERBIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	INPUT VALUE [1]
	df
	Unitless
Soil	0.05
Sediment	0.05
Water	0.20
Aquatic Plants, AP	0.70

[1] Estimated

Table 14. Deterministic Input Values for Variables Specific to Aquatic Plants Compartment

AQUATIC PLANTS SOURCE COMPARTMENTS	INPUT VALUE [1] df Unitless
Soil	0.05
Sediment	0.75
Water	0.20

[1] Estimated

The stochastic input ranges for each model variable are provided below in Tables 15 through 31. The ranges shown in Table 15 for the initial contaminant concentration, C_0, are again taken from published values for selenium contamination at Kesterson Reservoir, California (CH2M Hill 1986 and USBR 1990). All published contaminant concentration ranges, with the exception of the water selenium contaminant concentration, were reported as a minimum, maximum, and mean and therefore, a triangular distribution was assigned to each of these variables in the model. The water selenium contaminant concentration reported by CH2M Hill (1986) consisted of seventy-three data points. These data were analyzed with a probability distribution fitting software package and assigned a normal distribution. The results of the curve fitting analysis is provided as Appendix A.

Tables 16, 17, 18, and 19 list input ranges for endpoint contaminant concentrations, elimination rate constants, and assimilation efficiencies respectively for all biotic compartments. Tables 20 through 31 list the dietary fraction input ranges specific to each of the twelve biotic compartments. As previously mentioned, site- and contaminant-specific values for these variables were not found in the literature. In order to randomize these variables in the stochastic analysis, triangular ranges were created for each value by setting the maximum to 1.5 times the deterministic values and the minimum to 0.5 times the deterministic values. The deterministic value was used as the mean.

Table 15. Initial Se Contaminant Concentration, C_o, Stochastic Input Values for All Compartments

	INPUT RANGE (mg / [kg or L])			DISTRIBUTION TYPE
COMPARTMENT NAME	MIN	MAX	MEAN	
Soil [1]	1.000	85.000	7.000	Triangular
Sediment [1]	1.000	85.000	7.000	Triangular
Water [1]	standard deviation = 0.129		0.228	Normal
Top Carnivore, TC [1]	0.100	125.000	9.400	Triangular
Carnivorous Mammals, CM [1]	0.100	125.000	9.400	Triangular
Herbivorous Mammals, HM [1]	0.100	125.000	9.400	Triangular
Terrestrial Carnivorous Invertebrates, TCI [2]	2.000	84.000	10.200	Triangular
Terrestrial Herbivorous Invertebrates, THI [2]	0.400	42.000	7.800	Triangular
Terrestrial Plants, TP [1]	0.100	82.000	5.000	Triangular
Waterfowl, WF [1]	1.600	31.000	4.600	Triangular
Carnivorous Fish, CF [1]	2.000	200.000	135.000	Triangular
Herbivorous Fish, HF [1]	2.000	200.000	135.000	Triangular
Aquatic Carnivorous Invertebrates, ACI [2]	20.000	218.000	114.500	Triangular
Aquatic Herbivorous Invertebrates, ACI [2]	20.000	218.000	114.500	Triangular
Aquatic Plants, AP [1]	0.100	82.000	5.000	Triangular

[1] CH2M Hill (1986)
[2] USBR (1990)

Table 16. Endpoint Se Contaminant Concentration, C_e, Stochastic Input Values for Biotic Compartments

	INPUT RANGE (mg/kg) [1]			DISTRIBUTION TYPE
COMPARTMENT NAME	MIN	MAX	MEAN	
Top Carnivore, TC	50.000	150.000	100.000	Triangular
Carnivorous Mammals, CM	50.000	150.000	100.000	Triangular
Herbivorous Mammals, HM	50.000	150.000	100.000	Triangular
Terrestrial Carnivorous Invertebrates, TCI	50.000	150.000	100.000	Triangular
Terrestrial Herbivorous Invertebrates, THI	50.000	150.000	100.000	Triangular
Terrestrial Plants, TP	50.000	150.000	100.000	Triangular
Waterfowl, WF	50.000	150.000	100.000	Triangular
Carnivorous Fish, CF	125.000	375.000	250.000	Triangular
Herbivorous Fish, HF	125.000	375.000	250.000	Triangular
Aquatic Carnivorous Invertebrates, ACI	125.000	375.000	250.000	Triangular
Aquatic Herbivorous Invertebrates, ACI	125.000	375.000	250.000	Triangular
Aquatic Plants, AP	50.000	150.000	100.000	Triangular

[1] Estimated

Table 17. Se Uptake Rate Constants, k_u, Stochastic Input Values for Biotic Compartments

	INPUT RANGE ([kg or L] / mg/time) [1]			DISTRIBUTION TYPE
COMPARTMENT NAME	MIN	MAX	MEAN	
Top Carnivore, TC	0.020	0.060	0.040	Triangular
Carnivorous Mammals, CM	0.020	0.060	0.040	Triangular
Herbivorous Mammals, HM	0.025	0.075	0.050	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.010	0.030	0.020	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.025	0.075	0.050	Triangular
Terrestrial Plants, TP	0.030	0.090	0.060	Triangular
Waterfowl, WF	0.005	0.015	0.010	Triangular
Carnivorous Fish, CF	0.020	0.060	0.040	Triangular
Herbivorous Fish, HF	0.040	0.120	0.080	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.020	0.060	0.040	Triangular
Aquatic Herbivorous Invertebrates, ACI	0.040	0.120	0.080	Triangular
Aquatic Plants, AP	0.050	0.150	0.100	Triangular

[1] Adapted from Stehly (1990)

Table 18. Se Elimination Rate Constants, k_e, Stochastic Input Values for Biotic Compartments

	INPUT RANGE (time^{-1}) [1]			DISTRIBUTION TYPE
COMPARTMENT NAME	MIN	MAX	MEAN	
Top Carnivore, TC	0.001	0.003	0.002	Triangular
Carnivorous Mammals, CM	0.010	0.030	0.020	Triangular
Herbivorous Mammals, HM	0.010	0.030	0.020	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.005	0.015	0.010	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.010	0.030	0.020	Triangular
Terrestrial Plants, TP	0.010	0.030	0.020	Triangular
Waterfowl, WF	0.010	0.030	0.020	Triangular
Carnivorous Fish, CF	0.010	0.030	0.020	Triangular
Herbivorous Fish, HF	0.010	0.030	0.020	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.010	0.030	0.020	Triangular
Aquatic Herbivorous Invertebrates, ACI	0.010	0.030	0.020	Triangular
Aquatic Plants, AP	0.010	0.030	0.020	Triangular

[1] Adapted from Stehly (1990)

Table 19. Se Contaminant Assimilation Efficiency, eff, Stochastic Input Values for Biotic Compartments

	INPUT RANGE (unitless) [1]			DISTRIBUTION TYPE
COMPARTMENT NAME	MIN	MAX	MEAN	
Top Carnivore, TC	0.200	0.600	0.400	Triangular
Carnivorous Mammals, CM	0.175	0.525	0.350	Triangular
Herbivorous Mammals, HM	0.100	0.300	0.200	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.100	0.300	0.200	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.100	0.300	0.200	Triangular
Terrestrial Plants, TP	0.200	0.600	0.400	Triangular
Waterfowl, WF	0.035	0.105	0.070	Triangular
Carnivorous Fish, CF	0.100	0.300	0.200	Triangular
Herbivorous Fish, HF	0.100	0.300	0.200	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.100	0.300	0.200	Triangular
Aquatic Herbivorous Invertebrates, ACI	0.100	0.300	0.200	Triangular
Aquatic Plants, AP	0.200	0.600	0.400	Triangular

[1] Estimated

Table 20. Stochastic Input Values for Variables Specific to Top Carnivore Compartment

TOP CARNIVORE SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.050	0.150	0.100	Triangular
Carnivorous Mammals, CM	0.025	0.075	0.050	Triangular
Herbivorous Mammals, HM	0.150	0.450	0.300	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.050	0.150	0.100	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.050	0.150	0.100	Triangular
Waterfowl, WF	0.025	0.075	0.050	Triangular
Carnivorous Fish, CF	0.025	0.075	0.050	Triangular
Herbivorous Fish, HF	0.025	0.075	0.050	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.025	0.075	0.050	Triangular
Aquatic Herbivorous Invertebrates, AHI	0.025	0.075	0.050	Triangular

[1] Estimated

Table 21. Stochastic Input Values for Variables Specific to Carnivorous Mammals Compartment

CARNIVOROUS MAMMALS SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.050	0.150	0.100	Triangular
Herbivorous Mammals, HM	0.175	0.525	0.350	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.050	0.150	0.100	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.050	0.150	0.100	Triangular
Waterfowl, WF	0.025	0.075	0.050	Triangular
Carnivorous Fish, CF	0.025	0.075	0.050	Triangular
Herbivorous Fish, HF	0.025	0.075	0.050	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.025	0.075	0.050	Triangular
Aquatic Herbivorous Invertebrates, AHI	0.025	0.075	0.050	Triangular

[1] Estimated

Table 22. Stochastic Input Values for Variables Specific to Herbivorous Mammals Compartment

HERBIVOROUS MAMMALS SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless)[1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.050	0.150	0.100	Triangular
Terrestrial Plants, TP	0.350	1.050	0.700	Triangular
Aquatic Plants, AP	0.050	0.150	0.100	Triangular

[1] Estimated

Table 23. Stochastic Input Values for Variables Specific to Terrestrial Carnivorous Invertebrates Compartment

TERRESTRIAL CARNIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless)[1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.100	0.300	0.200	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.025	0.075	0.050	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.300	0.900	0.600	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.025	0.075	0.050	Triangular
Aquatic Herbivorous Invertebrates, AHI	0.025	0.075	0.050	Triangular

[1] Estimated

Table 24. Stochastic Input Values for Variables Specific to Terrestrial Herbivorous Invertebrates Compartment

TERRESTRIAL HERBIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless)[1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.050	0.150	0.100	Triangular
Sediment	0.050	0.150	0.100	Triangular
Water	0.025	0.075	0.050	Triangular
Terrestrial Plants, TP	0.350	1.050	0.700	Triangular
Aquatic Plants, AP	0.025	0.075	0.050	Triangular

[1] Estimated

Table 25. Stochastic Input Values for Variables Specific to Terrestrial Plants Compartment

TERRESTRIAL PLANTS SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.375	1.125	0.750	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.100	0.300	0.200	Triangular

[1] Estimated

Table 26. Stochastic Input Values for Variables Specific to Waterfowl Compartment

WATERFOWL SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.100	0.300	0.200	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.025	0.075	0.050	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.025	0.075	0.050	Triangular
Terrestrial Plants, TP	0.050	0.150	0.100	Triangular
Carnivorous Fish, CF	0.050	0.150	0.100	Triangular
Herbivorous Fish, HF	0.050	0.150	0.100	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.050	0.150	0.100	Triangular
Aquatic Herbivorous Invertebrates, AHI	0.050	0.150	0.100	Triangular
Aquatic Plants, AP	0.050	0.150	0.100	Triangular

[1] Estimated

Table 27. Stochastic Input Values for Variables Specific to Carnivorous Fish Compartment

CARNIVOROUS FISH SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.100	0.300	0.200	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.025	0.075	0.050	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.025	0.075	0.050	Triangular
Herbivorous Fish, HF	0.025	0.075	0.050	Triangular
Aquatic Carnivorous Invertebrates, ACI	0.025	0.075	0.050	Triangular
Aquatic Herbivorous Invertebrates, AHI	0.025	0.075	0.050	Triangular

[1] Estimated

Table 28. Stochastic Input Values for Variables Specific to Herbivorous Fish Compartment

HERBIVOROUS FISH SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.100	0.300	0.200	Triangular
Aquatic Plants, AP	0.035	1.050	0.700	Triangular

[1] Estimate

Table 29. Stochastic Input Values for Variables Specific to Aquatic Carnivorous Invertebrates Compartment

AQUATIC CARNIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.100	0.300	0.200	Triangular
Terrestrial Carnivorous Invertebrates, TCI	0.025	0.075	0.050	Triangular
Terrestrial Herbivorous Invertebrates, THI	0.025	0.075	.050	Triangular
Aquatic Herbivorous Invertebrates, AHI	0.300	0.900	0.600	Triangular

[1] Estimate

Table 30. Stochastic Input Values for Variables Specific to Aquatic Herbivorous Invertebrates Compartment

AQUATIC HERBIVOROUS INVERTEBRATES SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.025	0.075	0.050	Triangular
Water	0.100	0.300	0.200	Triangular
Aquatic Plants, AP	0.350	1.050	0.700	Triangular

[1] Estimate

Table 31. Stochastic Input Values for Variables Specific to Aquatic Plants Compartment

AQUATIC PLANTS SOURCE COMPARTMENTS	DIETARY FRACTION, df, (unitless) [1]			DISTRIBUTION TYPE
	INPUT RANGE			
	MIN	MAX	MEAN	
Soil	0.025	0.075	0.050	Triangular
Sediment	0.375	1.125	0.750	Triangular
Water	0.100	0.300	0.200	Triangular

[1] Estimate

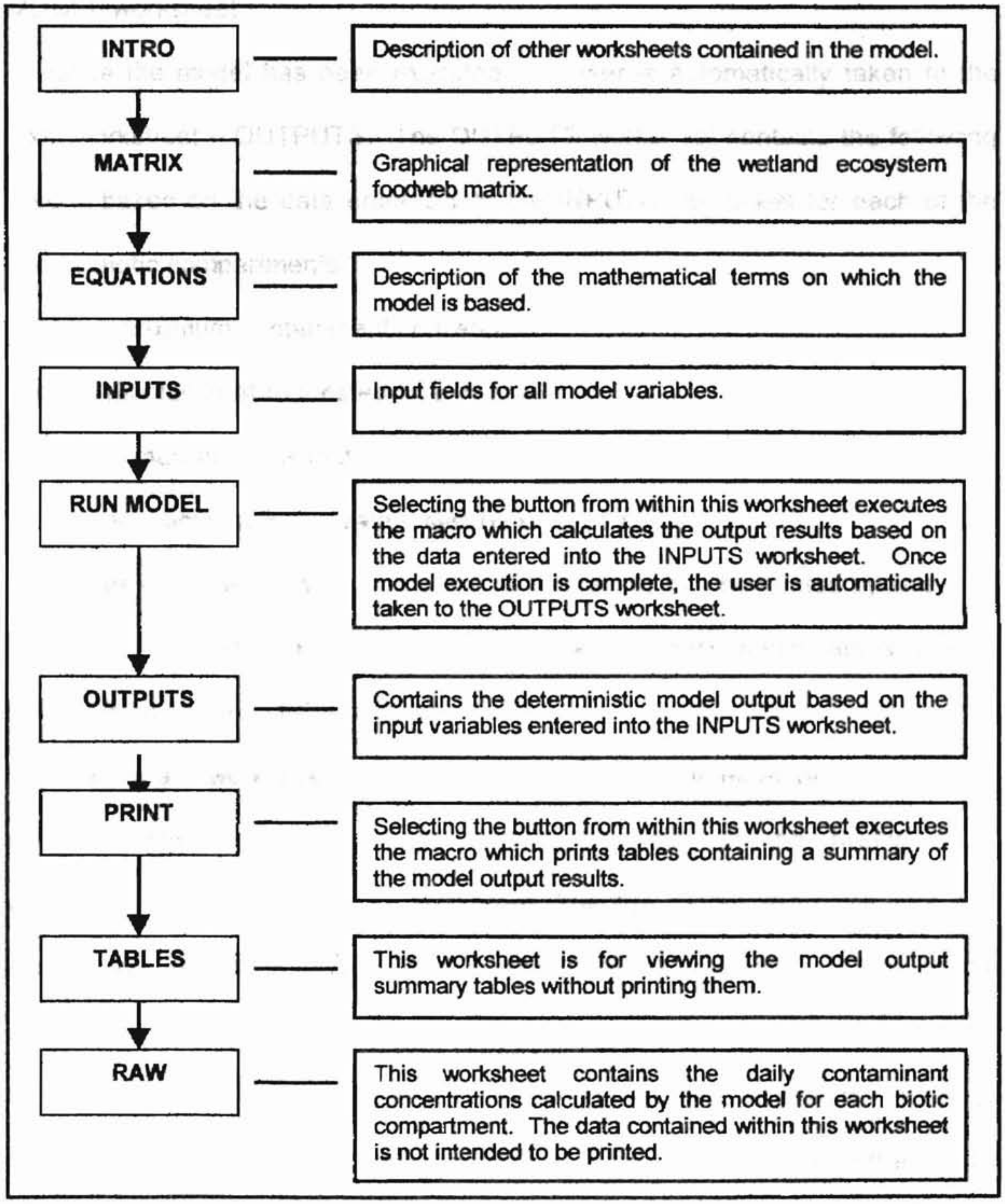
2.5 Model Development and Use

The model which has been described here can be incorporated into readily available personal computer spreadsheet software. For this work, Microsoft® Excel Version 7.0 was used. Lotus® 1-2-3, or other similar desktop spreadsheets would be equally acceptable for this type of analysis. The Monte Carlo sampling portion of the modeling employed the use of @RISK, Risk Analysis and Simulation Add-In for Microsoft® Excel or Lotus® 1-2-3 (Palisade 1996). BestFit, Probability Distribution Fitting for Windows®, a companion product to @RISK, was used as well to identify the distribution type for the water concentration contaminant level input range (Palisade 1998).

2.5.1 Environment and Architecture

As viewed from the spreadsheet, the model consists of nine worksheets. A flow diagram of the model is provided as Figure 4. The first worksheet, labeled INTRO, provides a brief description of the other eight worksheets and their contents. The INTRO worksheet also provides instruction on saving input parameters and output results.

The second worksheet, labeled MATRIX, includes a graphical representation of the simplified wetland ecosystem food web matrix similar to that of Figure 2. The third worksheet, EQUATIONS, provides a description of the mathematical terms on which the model is based.



INTRO — Description of other worksheets contained in the model.

MATRIX — Graphical representation of the wetland ecosystem foodweb matrix.

EQUATIONS — Description of the mathematical terms on which the model is based.

INPUTS — Input fields for all model variables.

RUN MODEL — Selecting the button from within this worksheet executes the macro which calculates the output results based on the data entered into the INPUTS worksheet. Once model execution is complete, the user is automatically taken to the OUTPUTS worksheet.

OUTPUTS — Contains the deterministic model output based on the input variables entered into the INPUTS worksheet.

PRINT — Selecting the button from within this worksheet executes the macro which prints tables containing a summary of the model output results.

TABLES — This worksheet is for viewing the model output summary tables without printing them.

RAW — This worksheet contains the daily contaminant concentrations calculated by the model for each biotic compartment. The data contained within this worksheet is not intended to be printed.

Figure 4. Model flow diagram.

The INPUTS worksheet contains input fields for all of the variables associated with the fifteen compartments which comprise the model. Upon entering all required input data, the model can be executed from the RUN MODEL worksheet.

Once the model has been executed, the user is automatically taken to the sixth worksheet – OUTPUTS. The OUTPUTS worksheet contains the following results based on the data entered into the INPUTS worksheet for each of the twelve biotic compartments:

C_{max}, maximum contaminant concentration;

RF_t, risk factor at requested time interval;

RF_{max}, maximum risk factor.

In order to calculate RF_t, a value must be entered for C_t.

Tables containing a summary of the model results can be printed by selecting the button located within the PRINT worksheet. These same tables can be viewed from the TABLES worksheet.

The final worksheet, RAW, contains the incremental contaminant concentrations calculated by the model for each of the twelve biotic compartments. It is from this worksheet that the model estimates risk and summarizes results in the OUTPUTS and TABLES worksheets. Due to the number of data points present in the raw data output, it exists only for the successful execution of the model and generation of desired results. Although the user can print and view these raw data, it could be rather awkward and time consuming and is therefore not recommended.

2.5.2 Saving Input Data and Output Results

Each time a new set of input parameters is entered into the model and the model is executed, the old input data and results are overwritten. Therefore, a companion file to the model, filename DATA.xls, was created that automatically updates the current input parameters and output results when opened simultaneously with the model, filename MODEL.xls. The user can manage the DATA.xls file as with any other Excel workbook. This will allow for efficient archiving and replication of previous data sets as well as to conserve disk space. The user should not corrupt the DATA.xls filename designation, but rather save previous work under another user-defined filename.

2.5.3 Automation

In an effort to increase efficiency and applicability, decrease confusion, and minimize human error, several steps within the model have been greatly simplified or completely automated via macros (see Appendix B for a complete listing of the macro code used for the model). Microsoft Excel employs the Visual Basic programming language for creating macros. The macros within the model allow the user to perform fairly simple tasks such as "point-and-click" printing of data tables and instantaneous archiving of current input variables and output data. A much more complex macro routine, developed for this research, greatly adds to the utility of the model. This macro allows the user to employ a wide range for the average life span variable without the need to repeatedly edit the raw data output range.

The initial portion of the code turns off the normal screen updating feature when the model is executed. This makes the macro more transparent and speeds up the model execution time (Walkenbach 1996).

```
Sub Run_Model()
   Application.ScreenUpdating = False
```

The next section of the code selects the RAW worksheet and then clears the existing raw data output from the previous model run for each of the twelve biotic compartments. Although only the top carnivore compartment code is shown in this excerpt, the code for the other compartments is similar.

```
      Sheets("RAW").Select
   'Clear previous TOP CARNIVORE results
      Range("B9").Select
      Range(ActiveCell, ActiveCell.End(xlDown)).Select
      Selection.Borders(xlLeft).LineStyle = xlNone
      Selection.Borders(xlRight).LineStyle = xlNone
      Selection.Borders(xlTop).LineStyle = xlNone
      Selection.Borders(xlBottom).LineStyle = xlNone
      Selection.BorderAround LineStyle:=xlNone
      Selection.ClearContents
      Range("C9").Select
      Range(ActiveCell, ActiveCell.End(xlDown)).Select
      Selection.Borders(xlLeft).LineStyle = xlNone
      Selection.Borders(xlRight).LineStyle = xlNone
      Selection.Borders(xlTop).LineStyle = xlNone
      Selection.Borders(xlBottom).LineStyle = xlNone
      Selection.BorderAround LineStyle:=xlNone
 Selection.ClearContents
```

The next section of the code calculates the new results for each abiotic compartment based on the data entered into the INPUTS worksheet. Notice the range reference format has changed from absolute (i.e., B8) to relative (i.e., 8,2). This allows the programmer to incorporate mathematical functions into the macro which in turn allows the modeler to manipulate the macro without actually changing the code. In this case, it allows the macro to handle potentially highly variable average life span input values. Again, only the top carnivore compartment is shown here.

```
'Calculate new results for TOP CARNIVORE
  Range(Cells(8, 2), Cells(8, 3)).Select
  Selection.Copy
  Range(Cells(8 + 1, 2), Cells(8 + (Cells(4, 3).Value - 1), 3)).Select
  ActiveSheet.Paste
  Application.CutCopyMode = False
  'Place bold line at bottom of Raw Output Results Table
  Range(Cells(8 + (Cells(4, 3).Value - 1), 2), Cells(8 + (Cells(4, 3).Value - 1), 3)).Select
  With Selection.Borders(xlBottom)
    .Weight = xlMedium
    .ColorIndex = xlAutomatic
  End With
'Return to cell A1 of RAW DATA OUTPUT worksheet
  Cells(1, 1).Select
```

The final portion of the code returns the user to the OUTPUTS worksheet where the model results can be viewed.

```
'Return to cell A1 of OUTPUTS worksheet
  Sheets("OUTPUTS").Select
  Cells(1, 1).Select
End Sub
```

2.6 Kesterson Reservoir Site Description

As mentioned, the data set used for this model was taken from selenium contamination at Kesterson Reservoir, California. The Kesterson site, as described by the USBR (1990) and Freedman (1995), in addition to twelve shallow ponds (1.0 – 1.5 m deep) totaling approximately 500 ha, is composed of four main habitat types. These are: (1) grasslands dominated by saltgrass (*Distichlis spicata*), (2) soil-filled former wetland areas dominated by annual plant species such as burning bush (*Kochia spp.*) and grasses, (3) open areas sparsely covered with burning bush (*Kochia spp.*), prickly lettuce (*Lactuca serriola*), and clover (*Melitotus spp.*), and (4) intermittent rainwater puddles. Due to the area's use as habitat by several important wildlife species and for human recreation, it has received much attention from ecologists regarding the high levels of selenium and other contaminant concentrations. The contaminant source was subsurface drainwaters from irrigated agricultural lands that were delivered to the reservoir via the San Luis Drain (CH2M Hill 1986). Delivery of this water to Kesterson was halted in mid-1986 (CH2M Hill 1986).

Effects of selenium overexposure at Kesterson were most noticeable in avian populations and included reproductive failure, reduced fecundity, and adult mortality (CH2M Hill 1986). Brain damage and other developmental abnormalities were highly prevalent among embryos and chicks (Freedman 1995). Several mammal species at Kesterson were shown to exhibit reduced reproductive success as compared to populations located at the Volta Wildlife Area (CH2M Hill 1986). Although no specific effects of overexposure were noticed for fish, invertebrates, and plants, Kesterson populations exhibited selenium levels of approximately 10 to 300 times higher than those of the reference wetland at the Volta Wildlife Area (Freedman 1995). Limited human health studies conducted on persons living adjacent to and working at the Kesterson site found selenium levels to be within normal ranges with no symptoms of overexposure (CH2M Hill 1986). Due to the levels of contamination found and the toxic effects witnessed, especially among bird populations, coupled with its ability to bioaccumulate, selenium was made the focus of risk assessment and mitigation efforts (CH2M Hill 1986).

Three levels of selenium removal were suggested by CH2M Hill (1986) and a risk assessment was performed for each as well as the original condition. The cleanup alternatives were: (1) a flexible response plan (FRP) consisting of "spot-removal" of contaminated soil and vegetation, (2) removal and on-site storage of 450,000 yd^3 (340,050 m^3) of soil and vegetation (ONSITE-1), and (3) removal and on-site storage of 1,000,000 yd^3 (764,555 m^3) of soil and vegetation (ONSITE-2). The ONSITE-1 and ONSITE-2 alternatives would have reportedly reduced the soil selenium concentrations to 3.0 and 1.5 mg/kg respectively. The CH2M Hill (1986) analysis culminated in a risk characterization for the site for each cleanup alternative using a stochastic approach to describe a range and likelihood of possible exposure scenarios under each cleanup alternative. This effort focussed upon the application of an alternative modeling technique to these suggested remediation levels. As with the CH2M Hill (1986) effort, the output results from the model developed for this work were used to compare the compartmental selenium contaminant concentrations under pre-clean-up conditions and the ONSITE-1 and ONSITE-2 mitigation alternatives.

2.7 Analytical Design

Models were prepared which compared several selenium contaminant scenarios for the Kesterson site. Scenarios 1 through 3 assume that the 1986 biotic compartmental selenium concentrations were not in a state of equilibrium (referred to as ASSUMPTION A). The C_e values employed for these scenarios were arbitrarily selected but critical to model performance. Scenarios 1 through 3 are defined as follows:

Scenario 1. Initial conditions present at 1986;

Scenario 2. Reduced soil, sediment, and water concentrations representative of ONSITE-1 cleanup goals with biotic compartment concentrations at 1986 levels; and

Scenario 3. Reduced soil, sediment, and water concentrations representative of ONSITE-2 cleanup goals with biotic compartment concentrations at 1986 levels.

The remaining five scenarios (4 through 6) assume that the biotic compartmental selenium concentrations reported by CH2M Hill (1986) and USBR (1990) represent conditions at equilibrium (referred to as ASSUMPTION B). For these analyses, the 1986 compartmental selenium concentrations were entered as the endpoint concentration (C_e) and the initial concentrations (C_o) were set to 0.01 mg/kg for all compartments. The 0.01 mg/kg value falls within the typical range for selenium in food (ASTDR 1989). Scenarios 4 through 6 are similar to 1 through 3 and are defined as follows:

Scenario 4. Initial conditions present at 1986;

Scenario 5. Reduced soil, sediment, and water concentrations representative of ONSITE-1 cleanup goals with biotic compartment endpoint concentrations (C_e) set at 1986 measured levels; and

Scenario 6. Reduced soil, sediment, and water concentrations representative of ONSITE-2 cleanup goals with biotic compartment endpoint concentrations (C_e) set at 1986 measured levels.

3. RESULTS

The deterministic output data returned the incremental contaminant concentration for each biotic compartment. This incremental selenium concentration was used to compare the time to C_e for each biotic compartment under the initial 1986 conditions (scenarios 1 and 4) and the ONSITE-1 (scenarios 2 and 5) and ONSITE-2 (scenarios 3 and 6) cleanup alternatives proposed by CH2M Hill (1986). The stochastic approach was used to (1) estimate the relative effects each of the input parameters had on the output results via a rank order correlation and (2) to generate and compare contaminant concentration probability distribution functions of each biotic compartment for the six modeled scenarios and two basic equilibrium assumptions.

3.1 Deterministic Output Data

The deterministic, or point, analysis was repeated three times under the two equilibrium state assumption criteria (once for each of the six described scenarios). Figures 5 through 28 compare the selenium concentration for each biotic compartment for scenarios 1 through 3 (ASSUMPTION A) and scenarios 4 through 6 (ASSUMPTION B) up to 100% of the endpoint concentration.

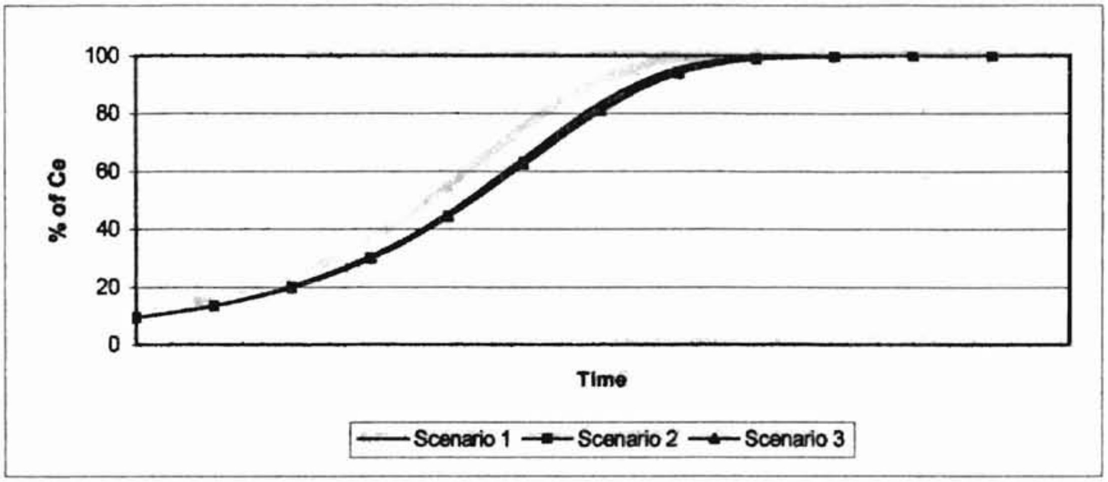


Figure 5. Top carnivore compartment time to 100% of endpoint concentration comparison.

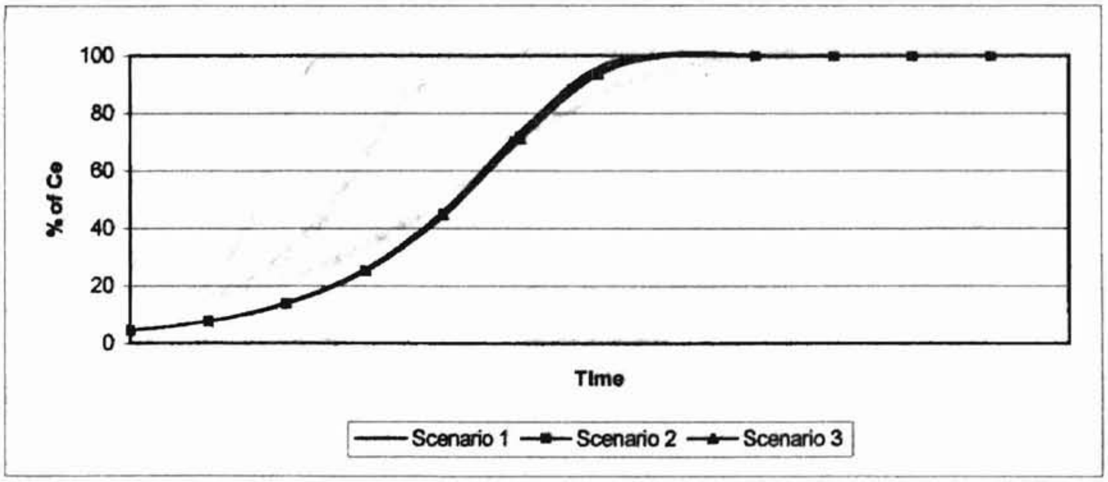


Figure 6. Waterfowl compartment time to 100% of endpoint concentration comparison.

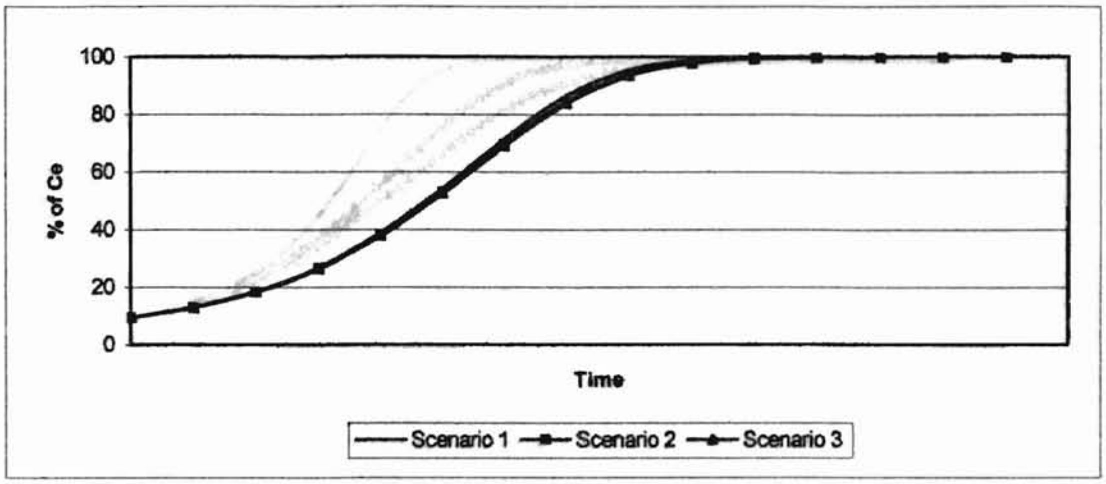


Figure 7. Carnivorous mammals compartment time to 100% of endpoint concentration comparison.

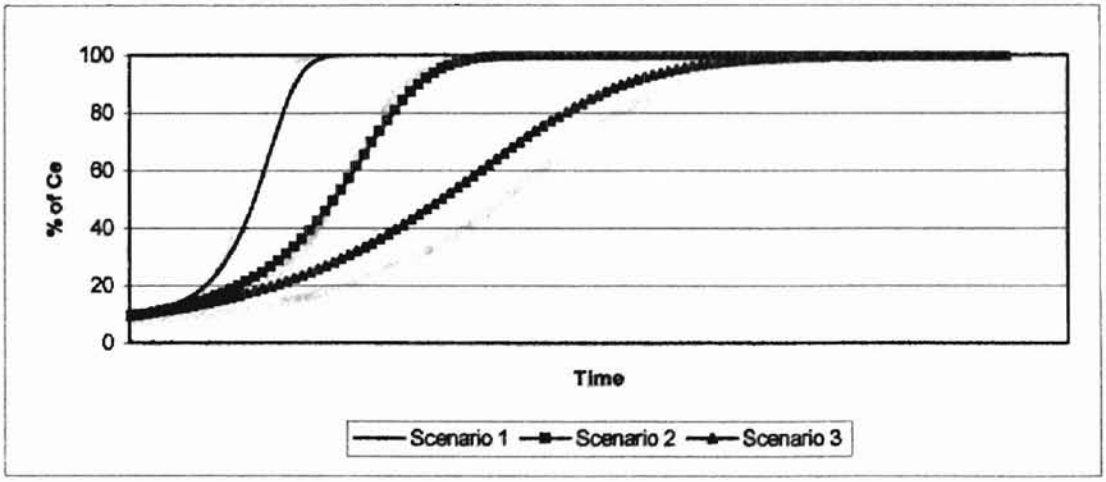


Figure 8. Herbivorous mammals compartment time to 100% of endpoint concentration comparison.

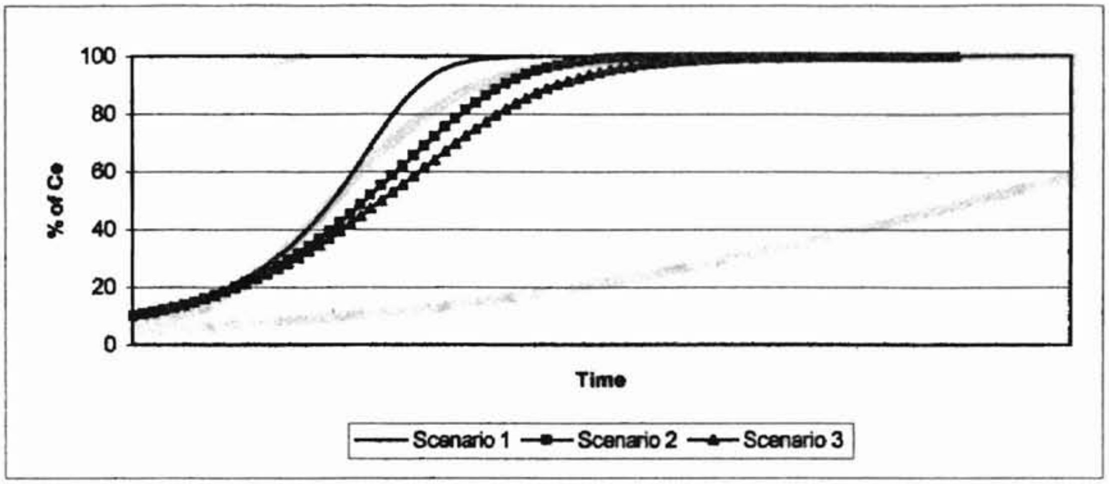


Figure 9. Terrestrial carnivorous invertebrates compartment time to 100% of endpoint concentration comparison.

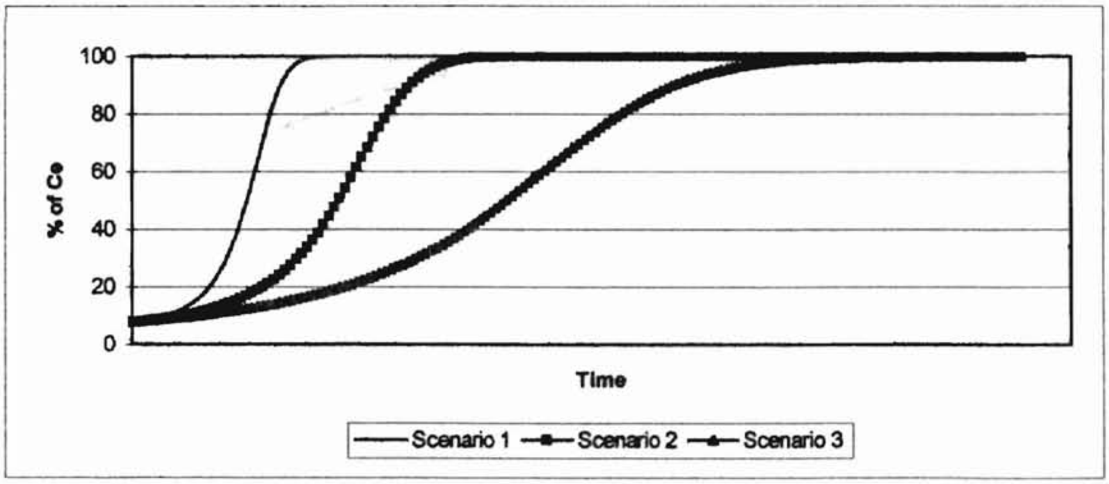


Figure 10. Terrestrial herbivorous invertebrates compartment time to 100% of endpoint concentration comparison.

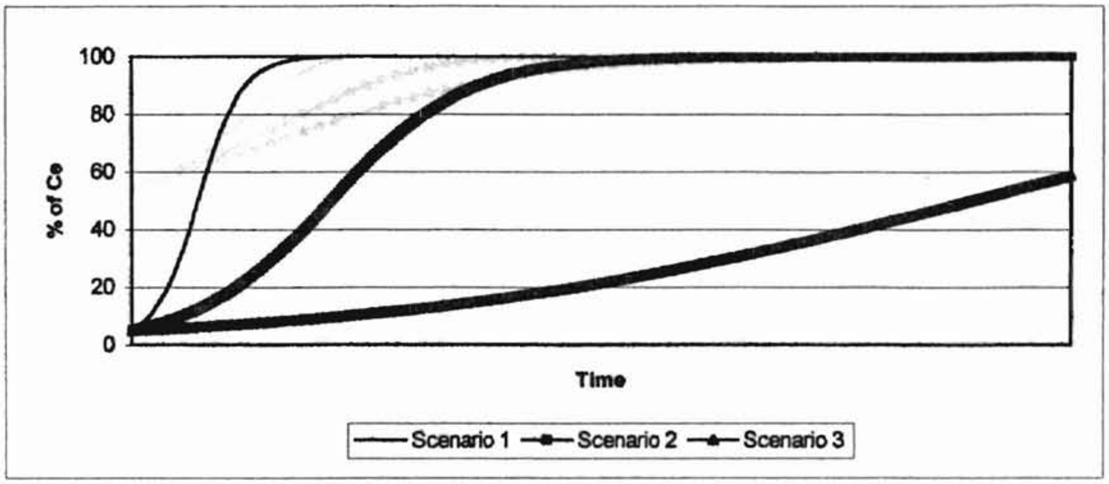


Figure 11. Terrestrial plants compartment time to 100% of endpoint concentration comparison.

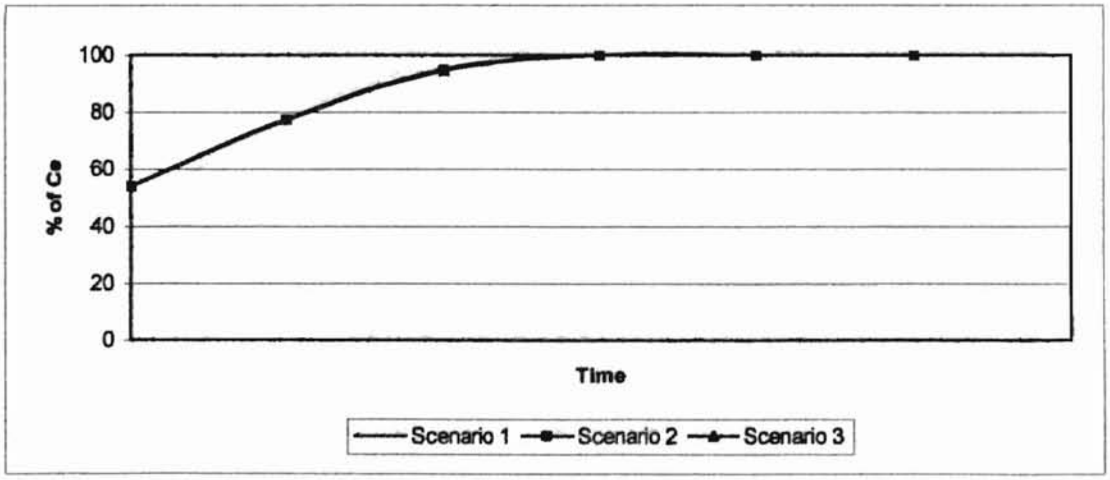


Figure 12. Carnivorous fish compartment time to 100% of endpoint concentration comparison.

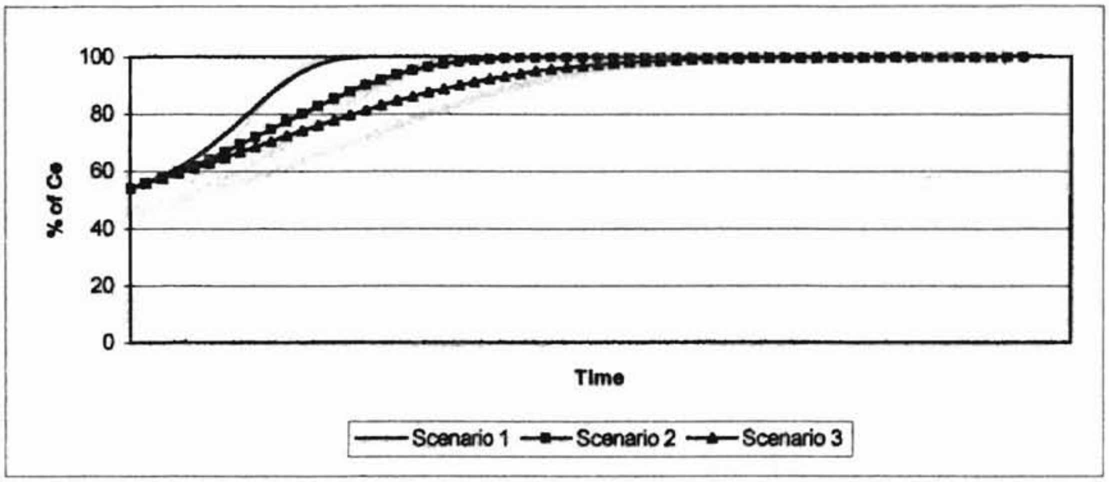


Figure 13. Herbivorous fish compartment time to 100% of endpoint concentration comparison.

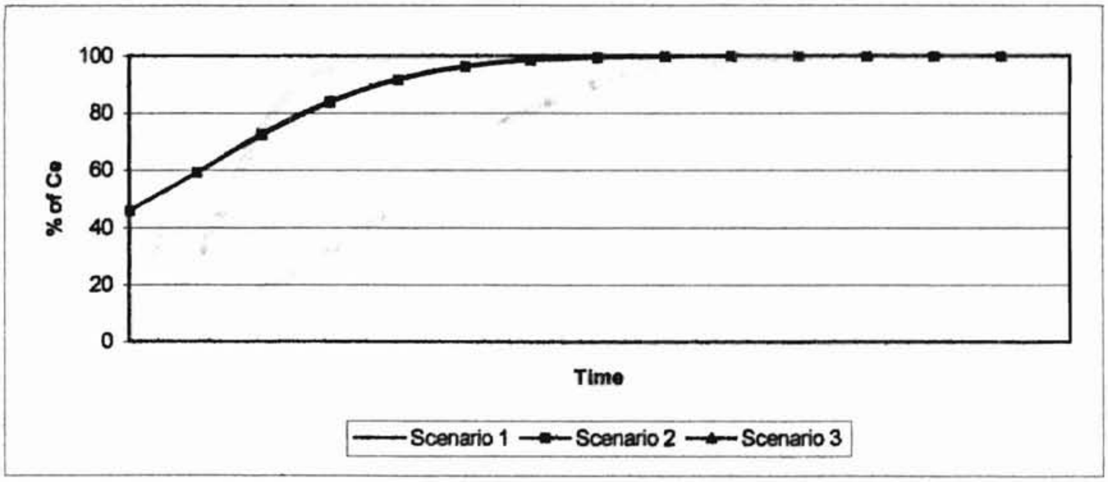


Figure 14. Aquatic carnivorous invertebrates compartment time to 100% of endpoint concentration comparison.

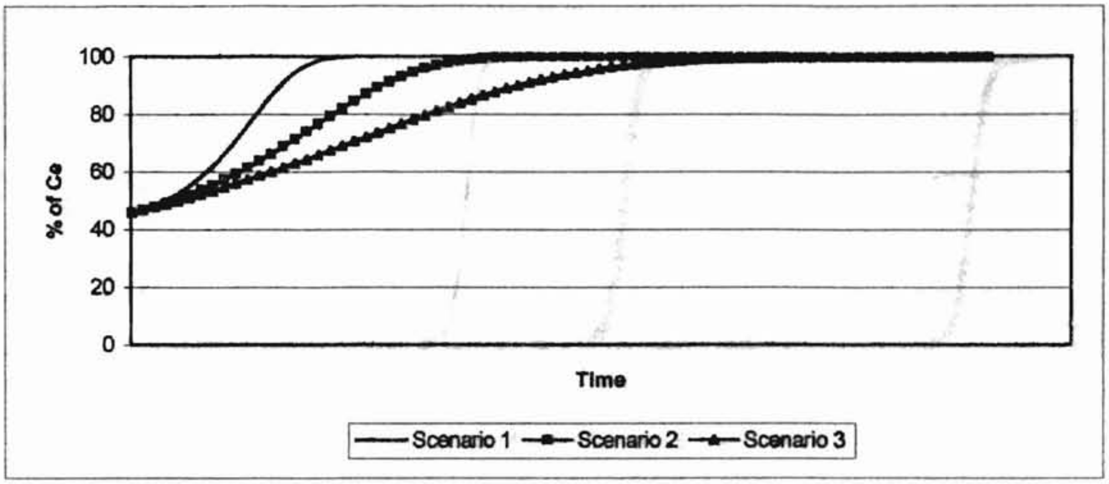


Figure 15. Aquatic herbivorous invertebrates compartment time to 100% of endpoint concentration comparison.

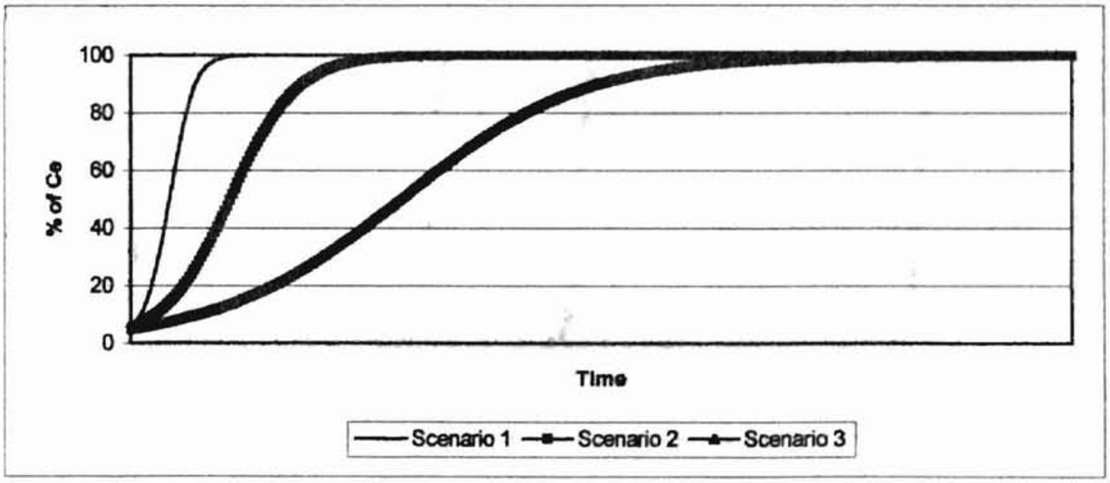


Figure 16. Aquatic plants compartment time to 100% of endpoint concentration comparison.

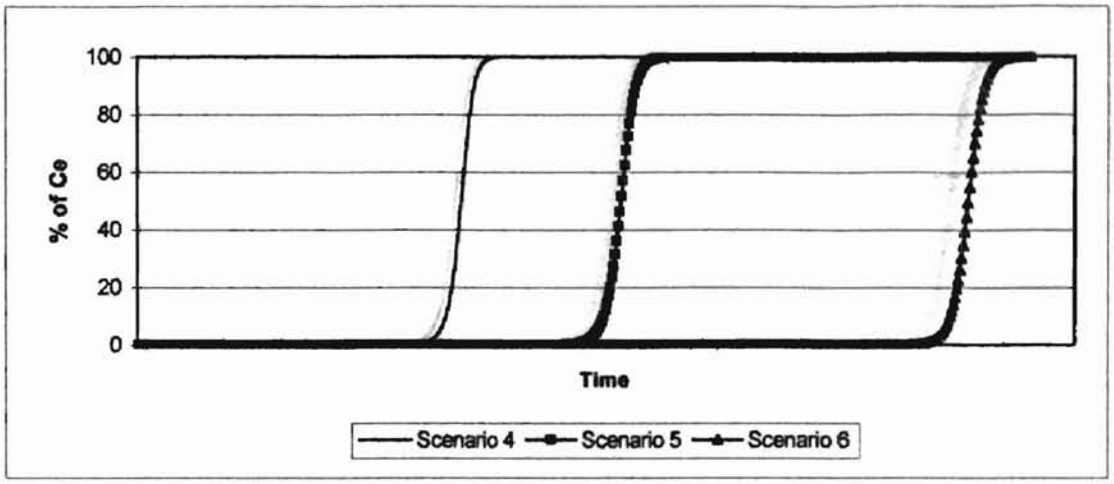


Figure 17. Top carnivore compartment time to 100% of endpoint concentration comparison.

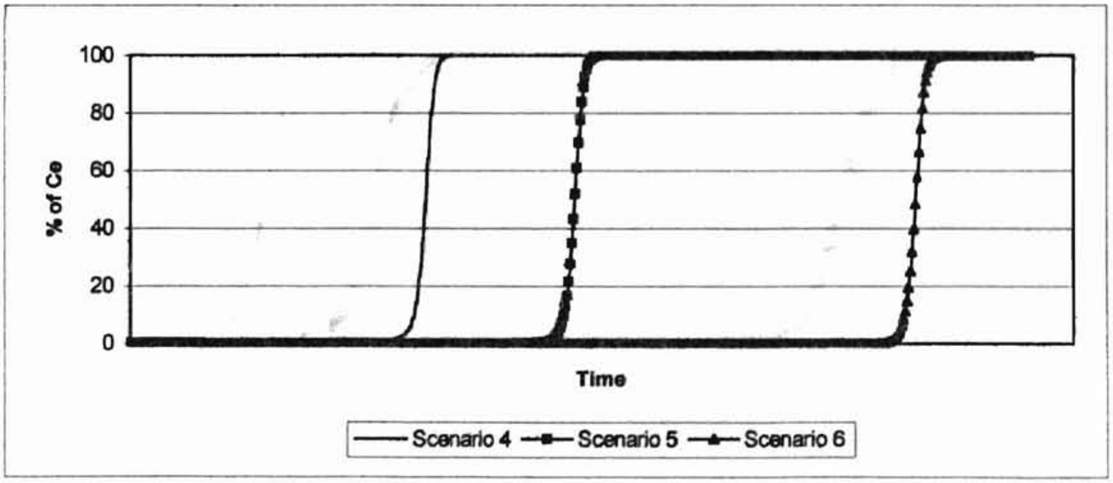


Figure 18. Waterfowl compartment time to 100% of endpoint concentration comparison.

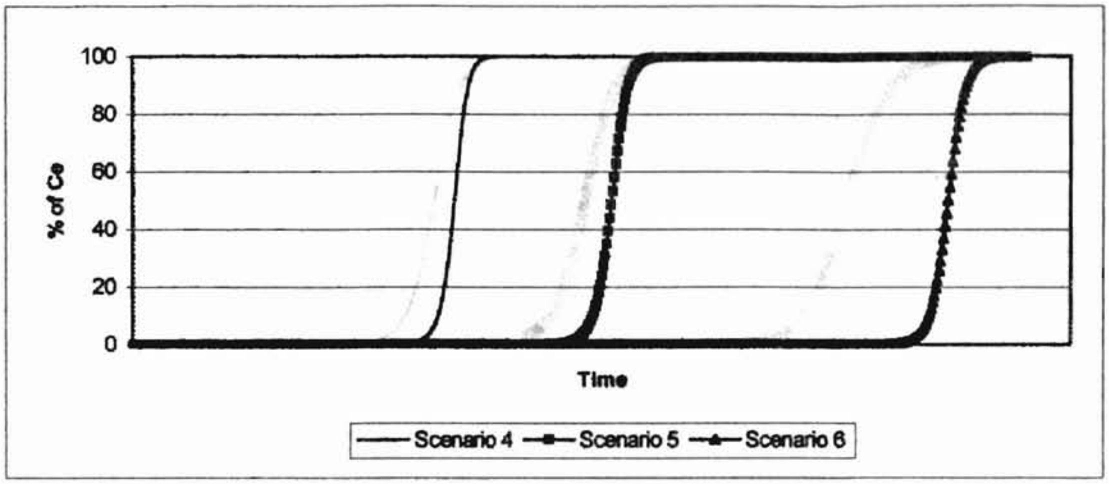


Figure 19. Carnivorous mammals compartment time to 100% of endpoint concentration comparison.

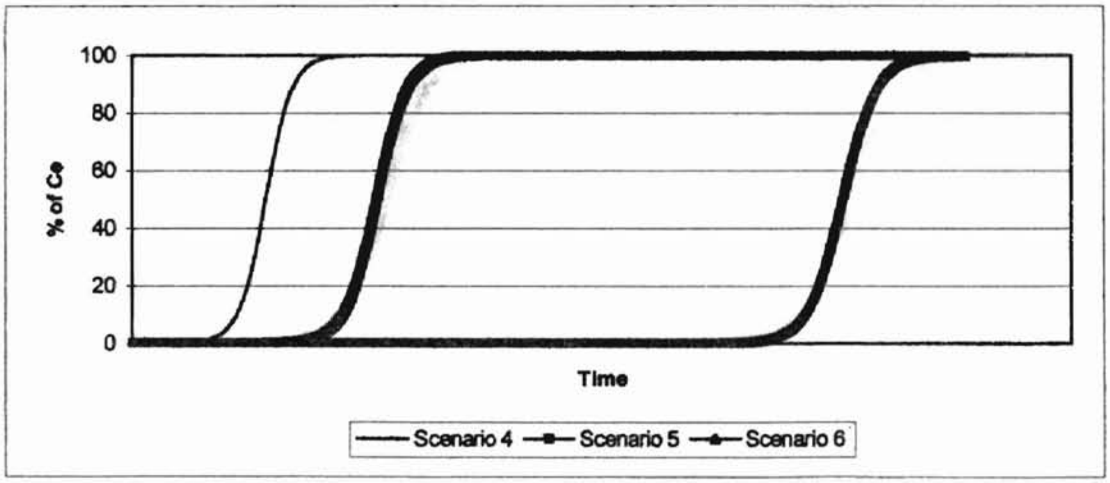


Figure 20. Herbivorous mammals compartment time to 100% of endpoint concentration comparison.

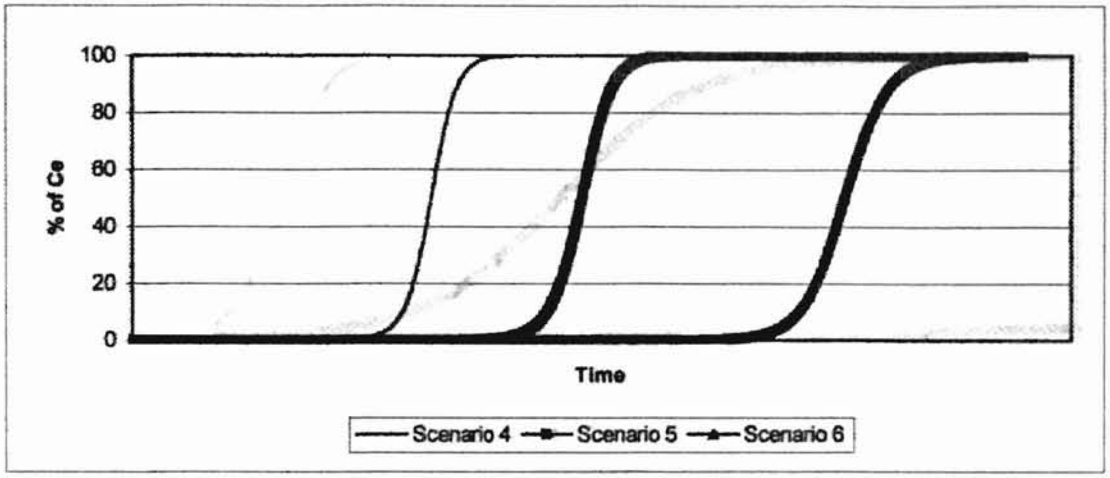


Figure 21. Terrestrial carnivorous invertebrates compartment time to 100% of endpoint concentration comparison.

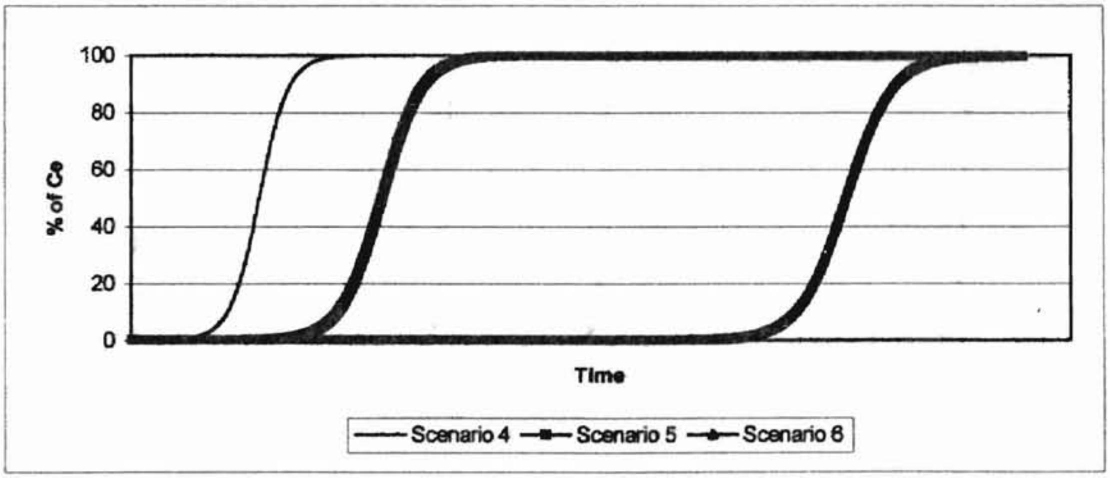


Figure 22. Terrestrial herbivorous invertebrates compartment time to 100% of endpoint concentration comparison.

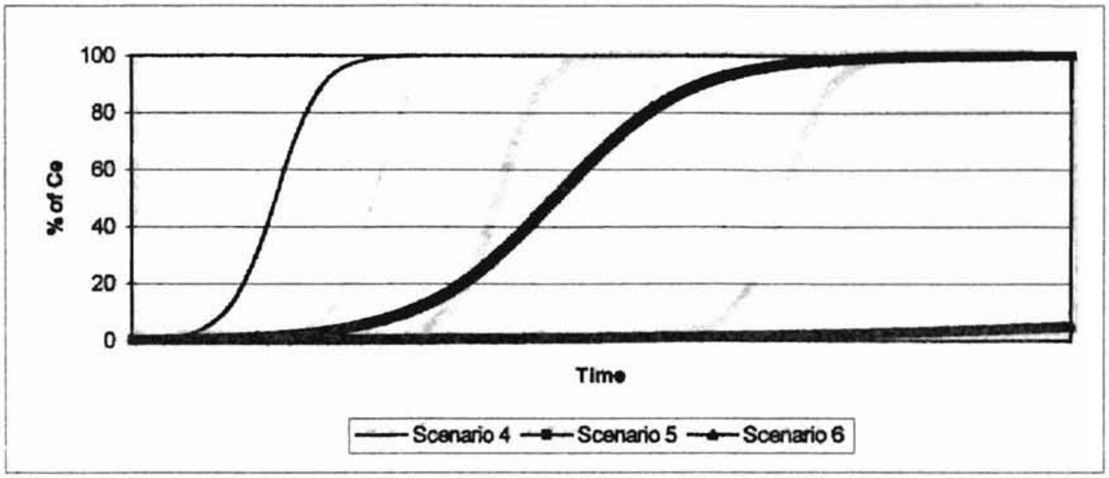


Figure 23. Terrestrial plants compartment time to 100% of endpoint concentration comparison.

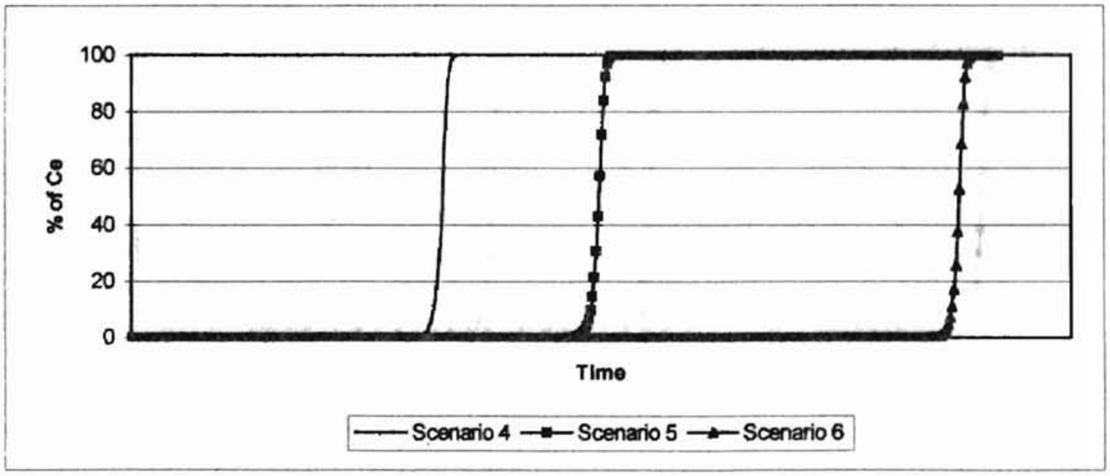


Figure 24. Carnivorous fish compartment time to 100% of endpoint concentration comparison.

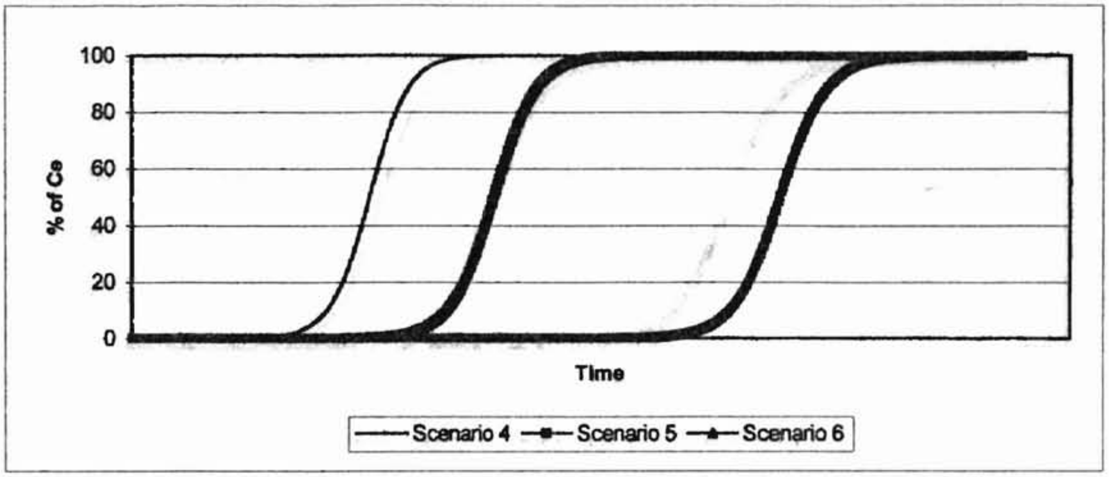


Figure 25. Herbivorous fish compartment time to 100% of endpoint concentration comparison.

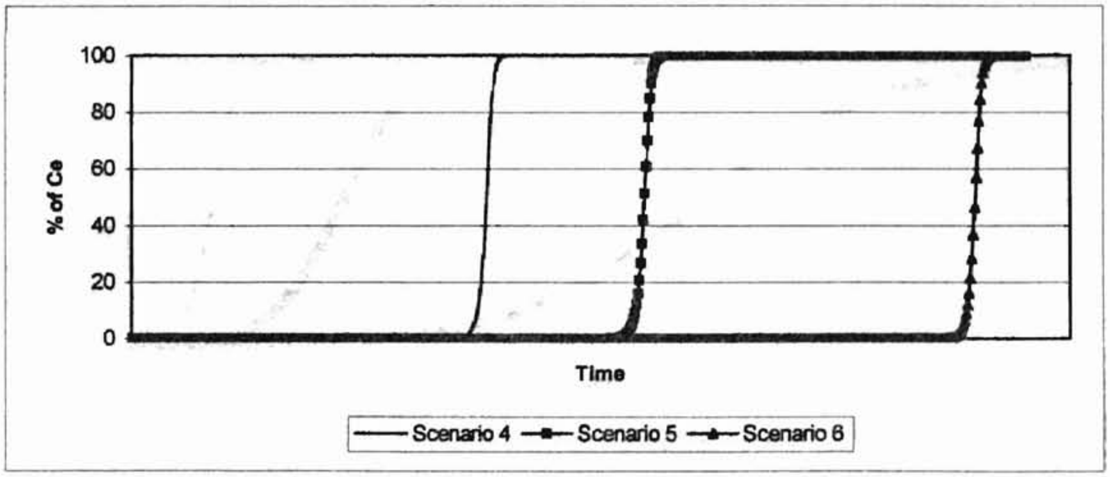


Figure 26. Aquatic carnivorous invertebrates compartment time to 100% of endpoint concentration comparison.

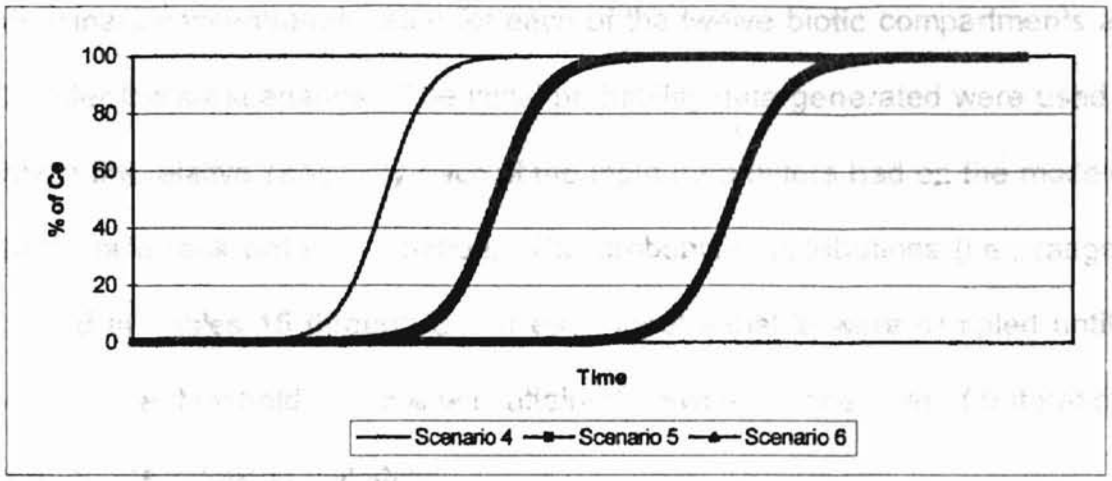


Figure 27. Aquatic herbivorous invertebrates compartment time to 100% of endpoint concentration comparison.

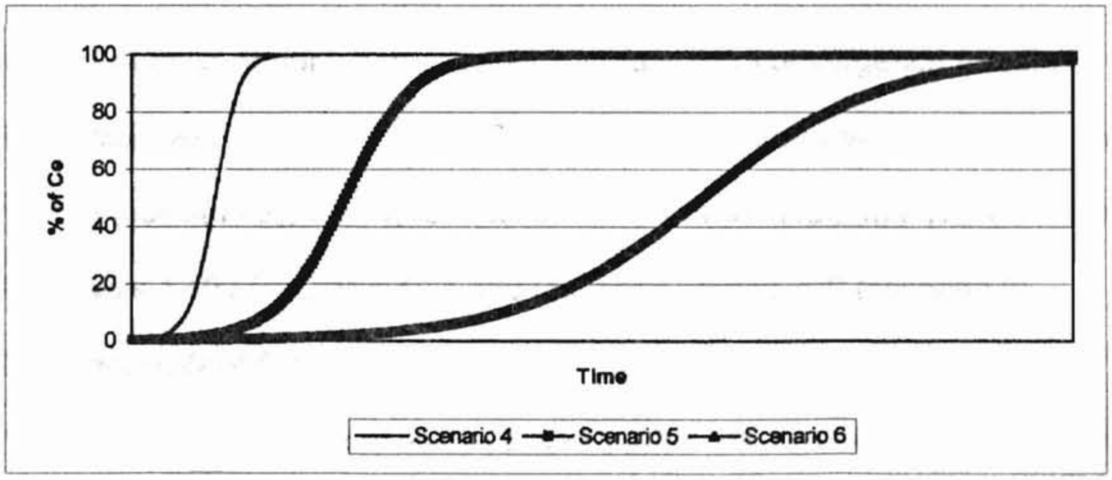


Figure 28. Aquatic plants compartment time to 100% of endpoint concentration comparison.

3.2 Stochastic Output Data

The stochastic estimate approach employed a Latin Hypercube sampling technique in order to generate probability distributions for the compartmental contaminant concentration value for each of the twelve biotic compartments at *t* = 1 under the six scenarios. The initial probability data generated were used to analyze the relative sensitivity each of the input parameters had on the modeled results via a rank order correlation. The probability distributions (i.e., ranges) provided in Tables 15 through 31 for each input variable were sampled until a convergence threshold of 1.5% was attained between successive 100 iterations based on the following statistics:

- percentiles
- mean
- standard deviation

The total number of iterations required to attain this convergence threshold for each of the five scenarios under ASSUMPTION A criteria was 1,400 (scenario 1), 1,300 (scenario 2), and 1,100 (scenario 3). Under ASSUMPTION B criteria the tally was 1,400 (scenario 4), 1,400 (scenario 5), and 700 (scenario 6).

3.2.1 Sensitivity of Outputs to Inputs

A rank order correlation analysis was performed to better understand the relative impact each of the uncertain input range variables had on the modeled results. A rank order correlation was chosen over a multivariate stepwise regression due to the very low R^2 value (i.e., < 1%) returned for all compartments. An R^2 value less than approximately 60% suggests that the linear multivariate stepwise regression does not sufficiently explain the relationship between the inputs and outputs (Palisade 1996). The results of the sensitivity analysis showed an almost perfect positive correlation between the modeled output and the initial contaminant concentration (C_o) for all compartments. The remaining input parameters showed extremely weak correlations, both positively and negatively. The sensitivity analysis was performed under ASSUMPTION A and B criteria with similar results.

3.2.2 Stochastic Output Result Ranges and Probability Distributions

Based on the input data ranges, the Latin Hypercube sampling analysis produced a range of possible values for each compartmental contaminant concentration ($C_{t=1}$). Probability distributions were also calculated for each compartment. The modeled ranges, means, standard deviations, and 25% and 75% confidence intervals, representing the intraquartile range, for each biotic compartment under each of the six scenarios are given in Tables 32 through 37. The probability distributions for each compartment under the six scenarios are presented as box and whisker diagrams in Figures 29 through 52. The upper and lower horizontal elements of each box represent the 75th and 25th percentiles respectively. The upper and lower vertical lines extend to the maximum and minimum selenium concentrations returned by the model under each scenario. Summary statistics for the stochastic analyses under the six scenarios are provided as Appendices C through H.

Table 32. Compartmental Se Stochastic Output Result Ranges, $C_{t=1}$ (mg/kg) under Scenario 1 – ASSUMPTION A Conditions

	TC	WF	CM	HM	TCI	THI	TP	CF	HF	ACI	AHI	AP
MAX	130.6	61.7	131.0	128.6	62.5	53.8	123.1	353.0	302.6	187.6	267.2	165.4
MIN	2.3	3.2	1.5	1.1	2.8	0.8	0.7	6.8	7.5	0.0	26.3	0.8
MEAN	54.2	20.1	54.5	50.3	31.9	20.9	39.2	157.5	139.3	79.7	136.1	45.4
SD	28.7	10.8	28.6	27.5	18.8	10.8	23.2	51.5	49.8	30.3	42.9	27.2
25%	29.5	11.7	30.3	27.4	15.8	12.0	19.7	126.0	106.9	59.6	106.0	23.3
75%	76.2	28.3	77.2	71.8	45.5	28.4	56.9	193.1	173.8	98.0	166.8	65.5

Table 33. Compartmental Se Stochastic Output Result Ranges, $C_{t=1}$ (mg/kg) under Scenario 2 – ASSUMPTION A Conditions

	TC	WF	CM	HM	TCI	THI	TP	CF	HF	ACI	AHI	AP
MAX	132.6	56.1	131.5	117.8	83.1	47.7	81.0	298.8	311.2	165.3	266.7	81.9
MIN	0.0	2.2	1.2	1.0	2.6	0.6	0.6	10.5	11.6	0.0	30.9	0.5
MEAN	56.6	20.5	53.0	49.5	32.4	19.1	29.2	154.9	136.1	81.1	133.2	29.4
SD	27.9	10.5	28.1	28.0	18.5	10.0	18.6	50.2	48.0	31.4	43.7	19.0
25%	34.5	11.5	29.2	26.2	16.6	11.0	13.3	124.0	105.9	61.3	101.1	13.1
75%	78.9	27.3	74.7	71.5	45.5	25.9	42.5	189.6	167.9	101.5	164.2	42.6

Table 34. Compartmental Se Stochastic Output Result Ranges, $C_{t=1}$ (mg/kg) under Scenario 3 – ASSUMPTION A Conditions

	TC	WF	CM	HM	TCI	THI	TP	CF	HF	ACI	AHI	AP
MAX	148.5	55.6	130.6	117.8	81.2	59.8	79.9	302.9	305.2	176.6	252.3	80.0
MIN	2.5	2.6	1.5	1.2	2.5	1.3	0.4	14.7	8.8	0.0	27.2	0.7
MEAN	55.8	20.1	54.2	50.9	31.5	19.5	29.0	155.3	136.7	80.1	132.4	29.2
SD	28.5	10.6	28.4	50.9	18.5	10.3	18.5	49.8	49.8	30.0	43.9	10.6
25%	33.3	11.6	29.8	25.4	15.6	10.7	13.3	121.4	102.4	60.5	99.9	13.0
75%	76.9	27.7	76.9	72.7	44.2	26.6	42.8	190.3	171.0	97.9	164.5	42.2

Table 35. Compartmental Se Stochastic Output Result Ranges, $C_{t=1}$ (mg/kg) under Scenario 4 – ASSUMPTION B Conditions

	TC	WF	CM	HM	TCI	THI	TP	CF	HF	ACI	AHI	AP
MAX	1.54E-02	1.56E-02	1.56E-02	1.59E-02	1.48E-02	1.68E-02	4.13E-02	1.51E-02	1.65E-02	1.47E-02	1.54E-02	6.94E-02
MIN	5.39E-03	5.30E-03	5.30E-03	5.21E-03	5.23E-03	5.08E-03	6.09E-03	5.19E-03	5.28E-03	5.15E-03	5.12E-03	6.14E-03
MEAN	1.04E-02	1.02E-02	1.02E-02	1.03E-02	9.92E-03	1.04E-02	1.57E-02	1.01E-02	1.05E-02	9.99E-03	1.02E-02	1.96E-02
SD	2.10E-03	2.10E-03	2.13E-03	2.17E-03	2.01E-03	2.20E-03	5.34E-03	2.13E-03	2.24E-03	1.98E-03	2.09E-03	8.31E-03
25%	8.89E-03	8.74E-03	8.75E-03	8.71E-03	8.48E-03	8.82E-03	1.19E-02	8.64E-03	8.84E-03	8.54E-03	8.75E-03	1.38E-02
75%	1.19E-02	1.17E-02	1.17E-02	1.18E-02	1.14E-03	1.20E-02	1.85E-02	1.16E-02	1.21E-02	1.15E-02	1.17E-02	2.37E-02

Table 36. Compartmental Se Stochastic Output Result Ranges, $C_{t=1}$ (mg/kg) under Scenario 5 – ASSUMPTION B Conditions

	TC	WF	CM	HM	TCI	THI	TP	CF	HF	ACI	AHI	AP
MAX	1.46E-02	1.47E-02	1.44E-02	1.46E-02	1.48E-02	1.46E-02	1.54E-02	1.47E-02	1.46E-02	1.48E-02	1.47E-02	1.67E-02
MIN	4.99E-03	4.99E-03	5.09E-03	5.06E-03	5.11E-03	5.11E-03	5.42E-03	5.06E-03	5.05E-03	5.24E-03	5.11E-03	5.28E-03
MEAN	1.00E-02	9.91E-03	9.94E-03	9.85E-03	9.80E-03	9.89E-03	1.03E-02	9.82E-03	9.85E-03	1.01E-02	9.80E-03	1.06E-02
SD	2.06E-03	2.04E-03	2.02E-03	2.03E-03	2.03E-03	2.03E-03	2.09E-03	2.05E-03	1.99E-03	2.06E-03	2.07E-03	2.20E-03
25%	8.54E-03	8.46E-03	8.58E-03	8.29E-03	8.30E-03	8.38E-03	8.82E-03	8.35E-03	8.50E-03	8.61E-03	8.37E-03	9.03E-03
75%	1.15E-02	1.14E-02	1.15E-02	1.13E-02	1.12E-03	1.13E-02	1.18E-02	1.13E-02	1.13E-02	1.16E-02	1.13E-02	1.22E-02

Table 37. Compartmental Se Stochastic Output Result Ranges, $C_{t=1}$ (mg/kg) under Scenario 6 – ASSUMPTION B Conditions

	TC	WF	CM	HM	TCI	THI	TP	CF	HF	ACI	AHI	AP
MAX	1.45E-02	1.45E-02	1.44E-02	1.45E-02	1.48E-02	1.45E-02	1.48E-02	1.45E-02	1.47E-02	1.45E-02	1.45E-02	1.55E-02
MIN	5.06E-03	5.21E-03	5.06E-03	4.98E-03	5.11E-03	5.14E-03	5.21E-03	4.96E-03	5.06E-03	5.08E-03	5.19E-03	5.47E-03
MEAN	9.67E-03	9.89E-03	9.74E-03	9.82E-03	9.98E-03	9.84E-03	1.01E-02	9.80E-03	9.74E-03	1.00E-02	9.92E-03	1.03E-02
SD	2.05E-03	1.93E-03	1.94E-03	1.99E-03	2.02E-03	1.98E-03	1.98E-03	2.01E-03	2.01E-03	1.99E-03	2.00E-03	2.11E-03
25%	8.26E-03	8.53E-03	8.26E-03	8.36E-03	8.56E-03	8.42E-03	8.82E-03	8.38E-03	8.32E-03	8.64E-03	8.42E-03	8.75E-03
75%	1.14E-02	1.13E-02	1.12E-02	1.12E-02	1.15E-03	1.12E-02	1.15E-02	1.12E-02	1.11E-02	1.14E-02	1.14E-02	1.19E-02

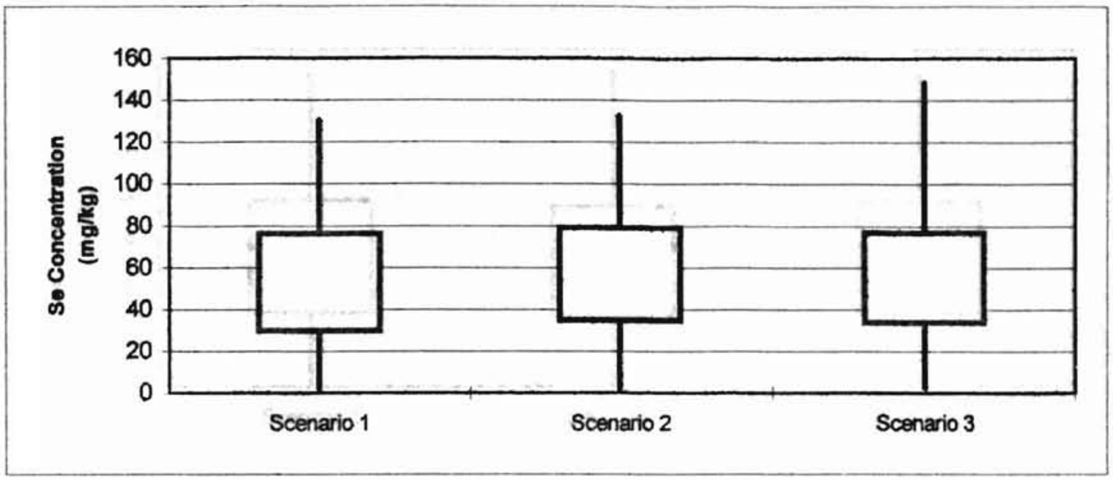


Figure 29. Probability distribution comparison for top carnivore compartment.

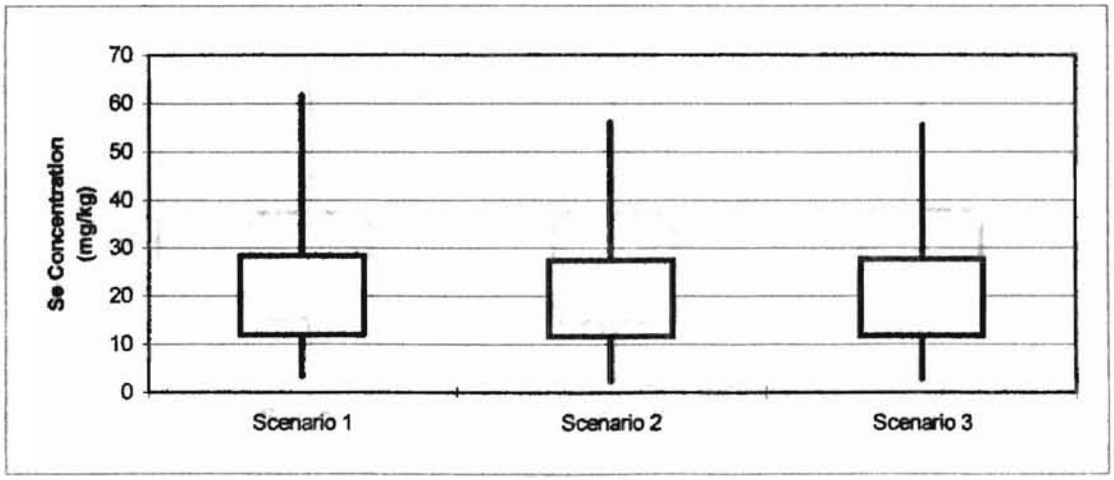


Figure 30. Probability distribution comparison for waterfowl compartment.

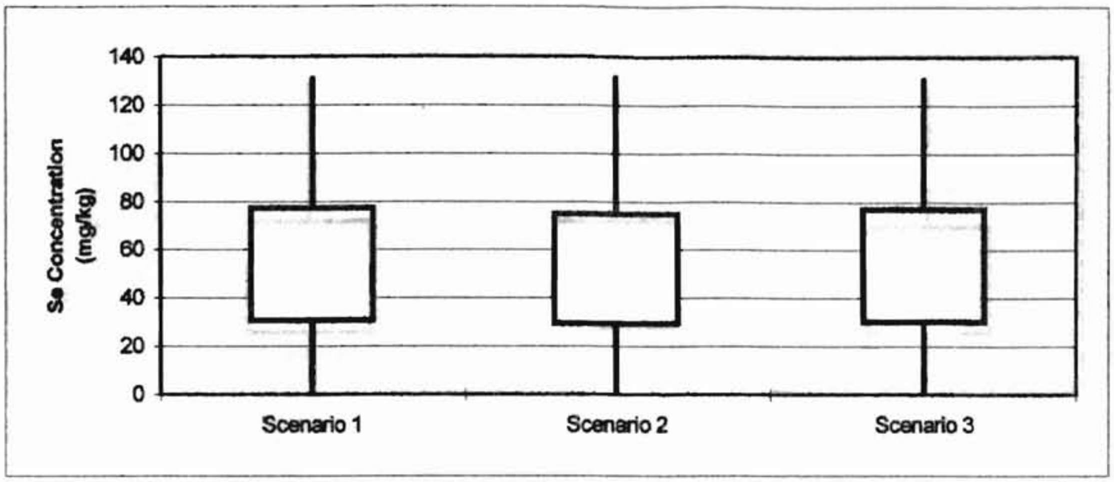


Figure 31. Probability distribution comparison for carnivorous mammals compartment.

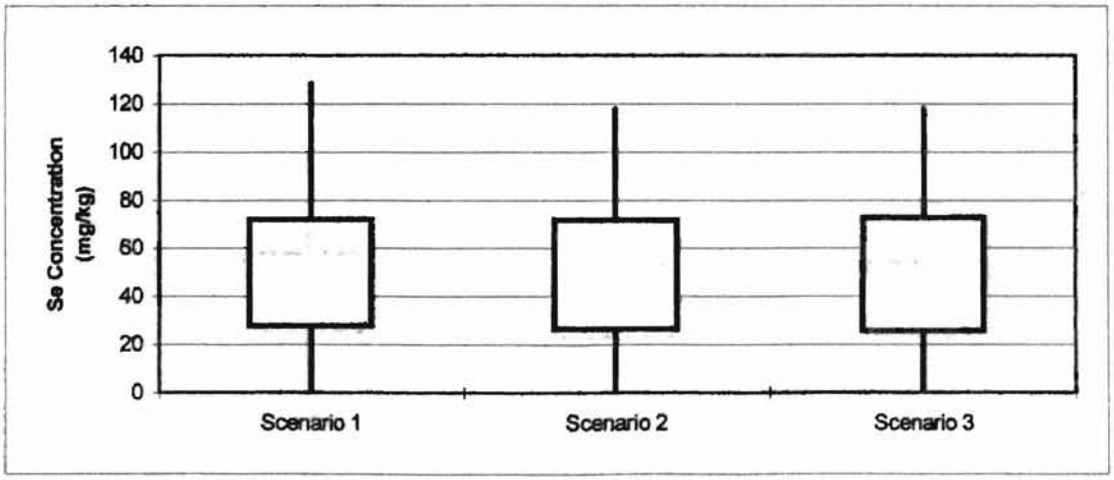


Figure 32. Probability distribution comparison for herbivorous mammals compartment.

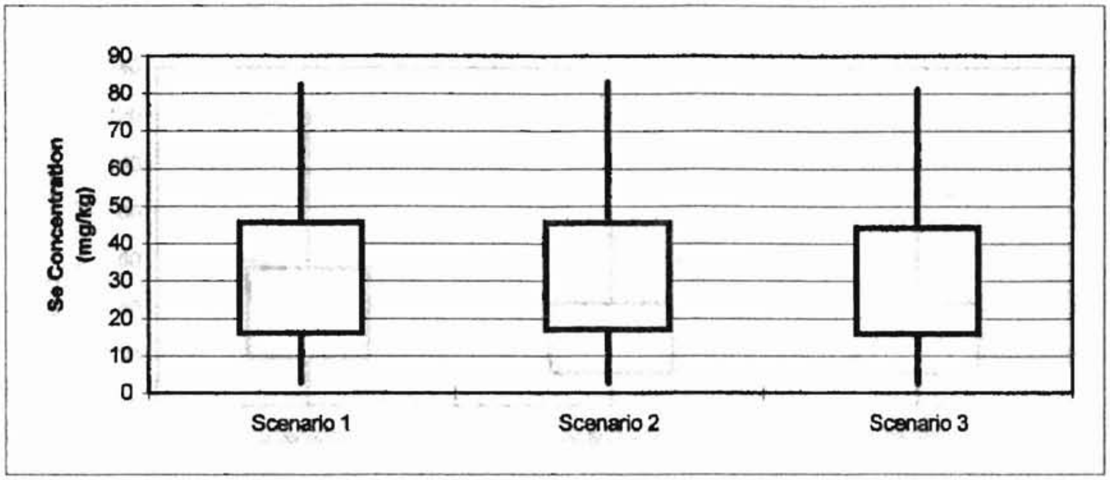


Figure 33. Probability distribution comparison for terrestrial carnivorous invertebrates compartment.

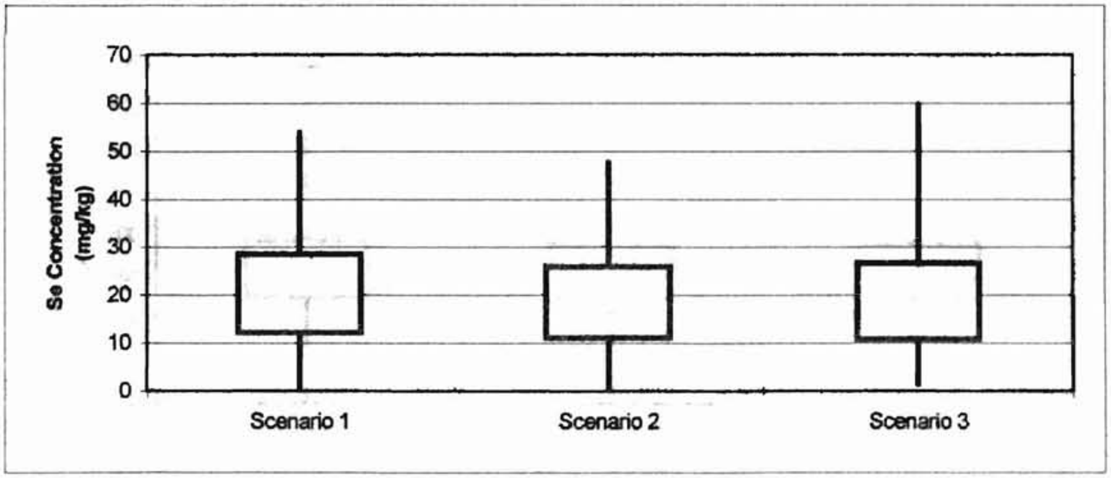


Figure 34. Probability distribution comparison for terrestrial herbivorous invertebrates compartment.

Figure 35. Probability distribution comparison for terrestrial plants compartment.

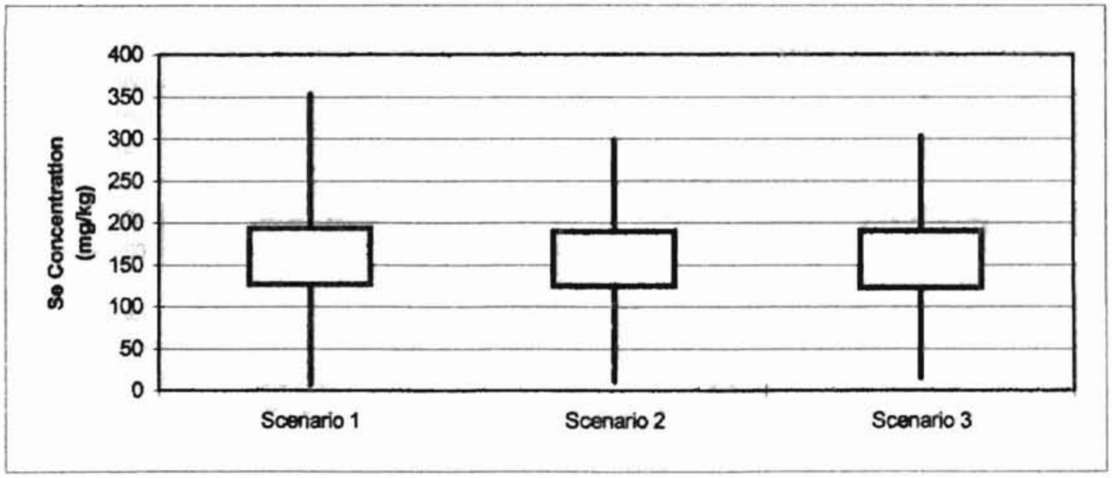


Figure 36. Probability distribution comparison for carnivorous fish compartment.

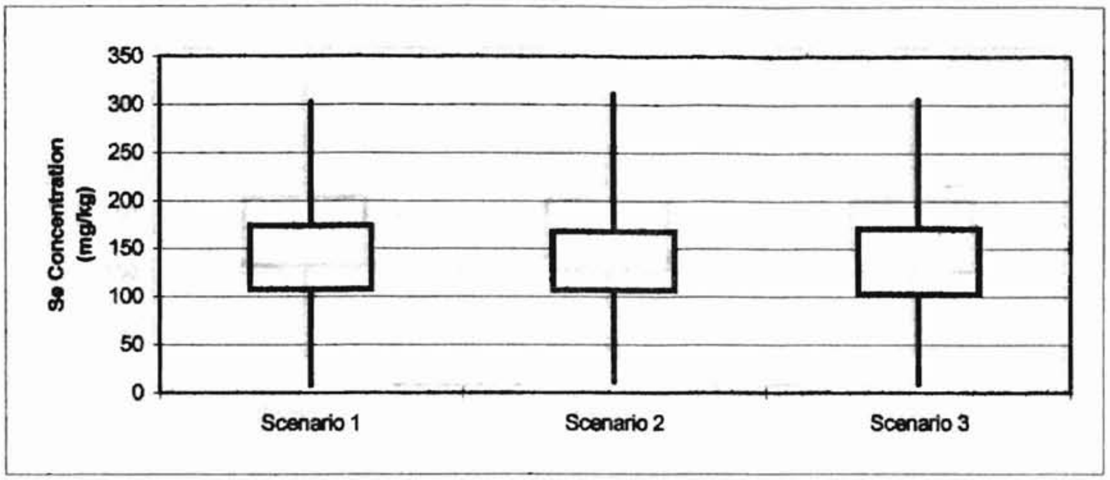


Figure 37. Probability distribution comparison for herbivorous fish compartment.

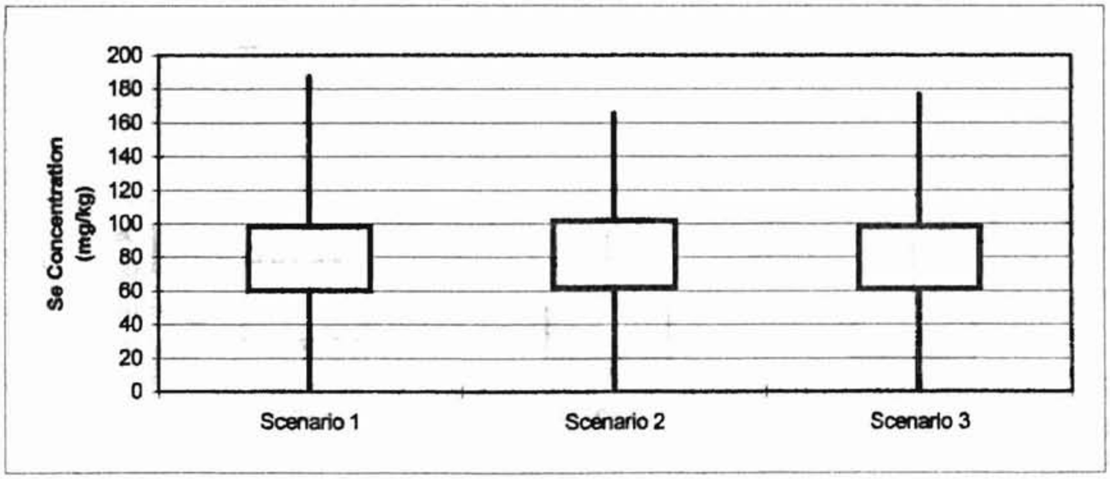


Figure 38. Probability distribution comparison for aquatic carnivorous invertebrates compartment.

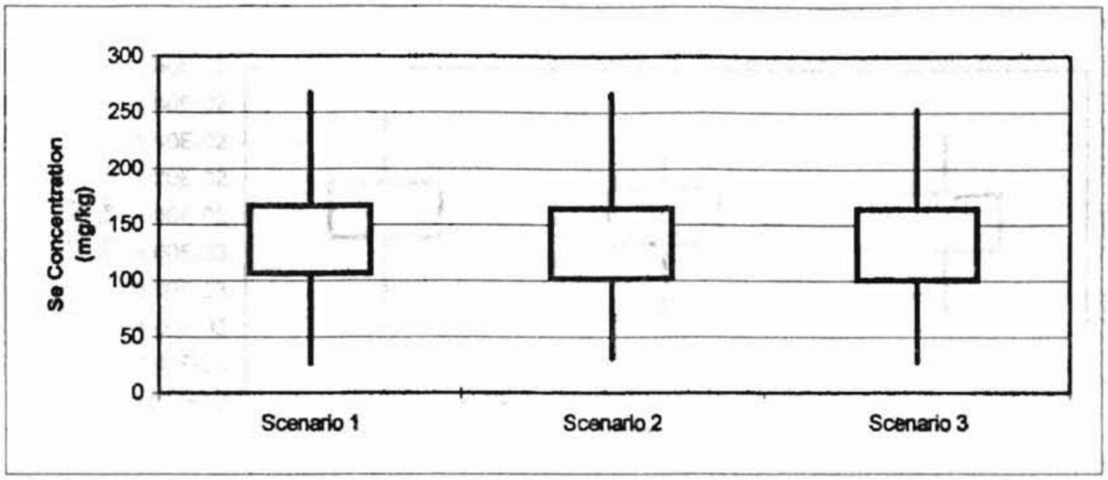


Figure 39. Probability distribution comparison for aquatic herbivorous invertebrates compartment.

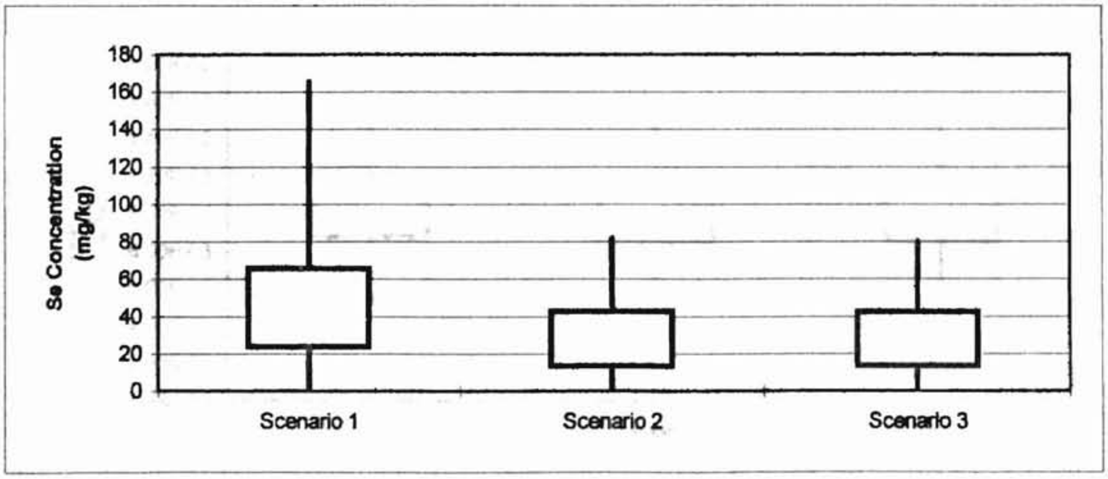


Figure 40. Probability distribution comparison for aquatic plants compartment.

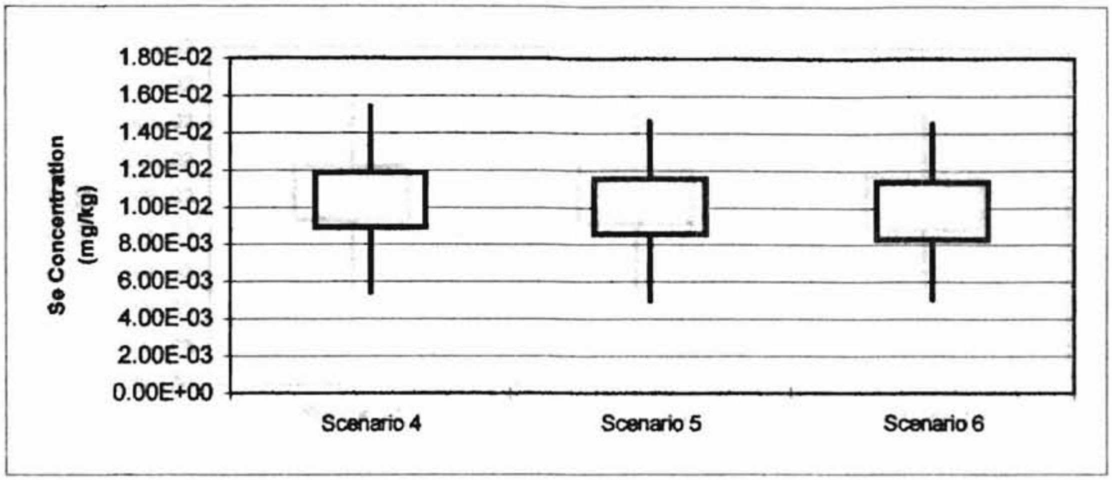


Figure 41. Probability distribution comparison for top carnivore compartment.

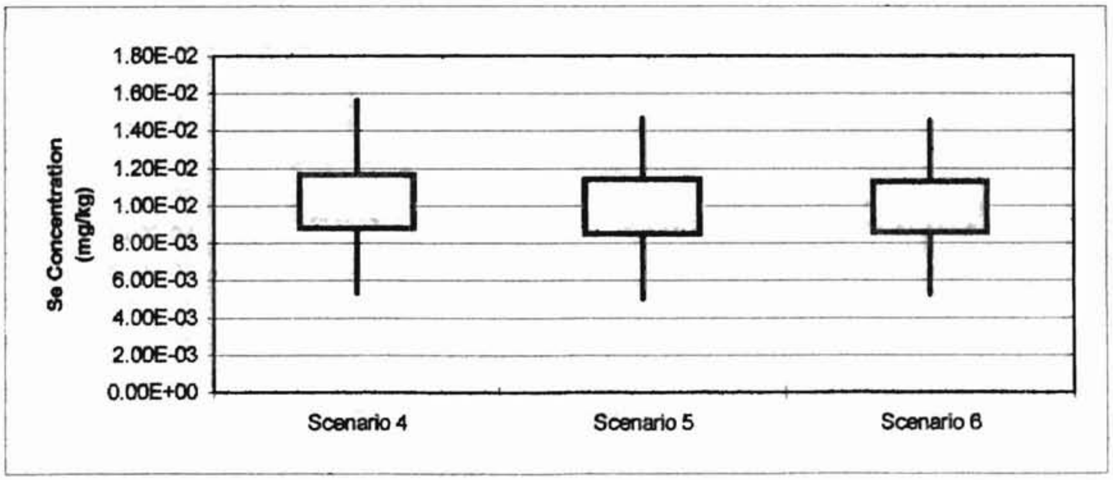


Figure 42. Probability distribution comparison for waterfowl compartment.

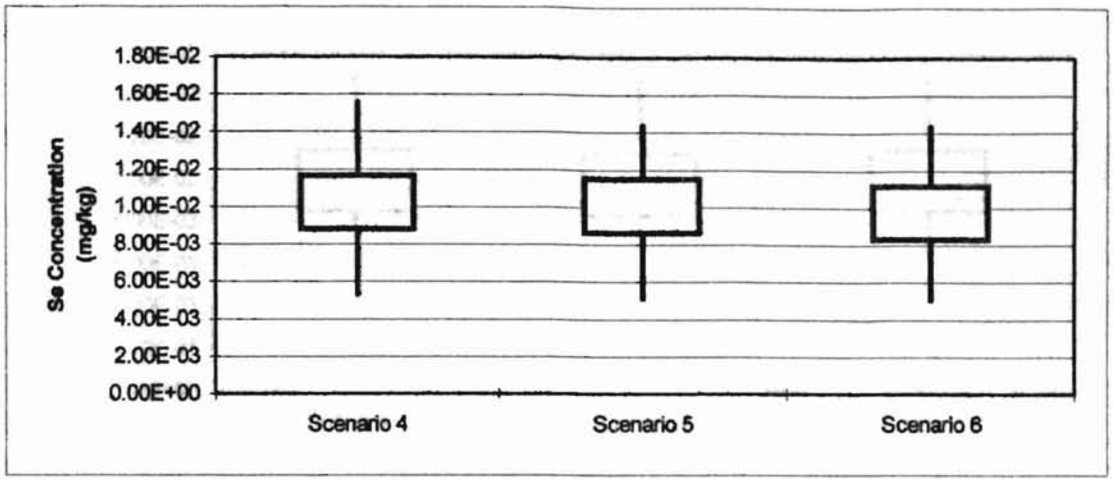


Figure 43. Probability distribution comparison for carnivorous mammals compartment.

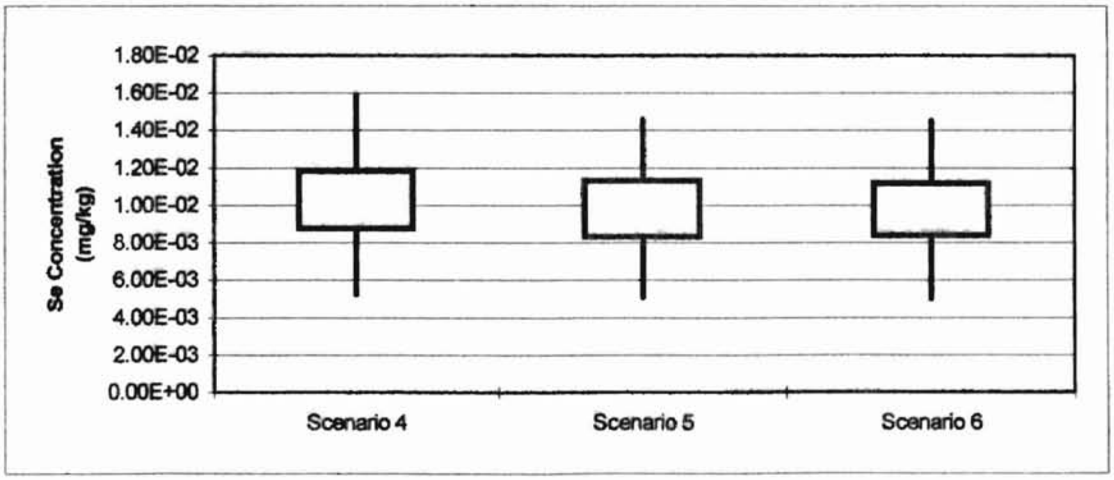


Figure 44. Probability distribution comparison for herbivorous mammals compartment.

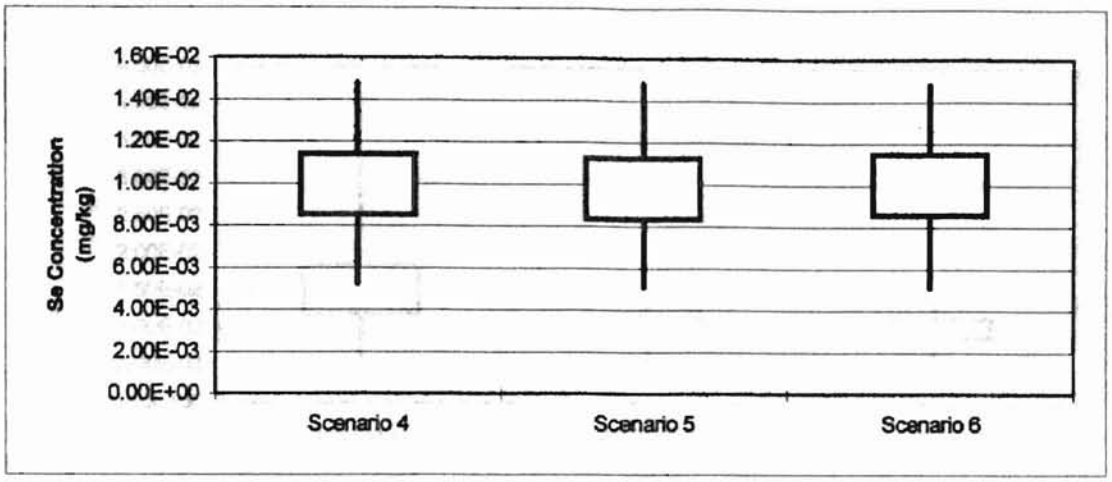


Figure 45. Probability distribution comparison for terrestrial carnivorous invertebrates compartment.

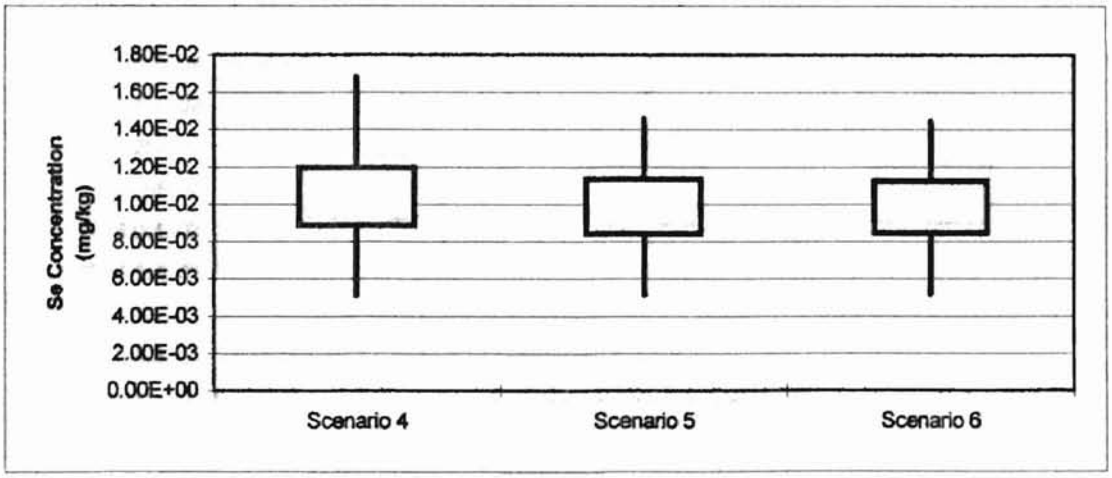


Figure 46. Probability distribution comparison for terrestrial herbivorous invertebrates compartment.

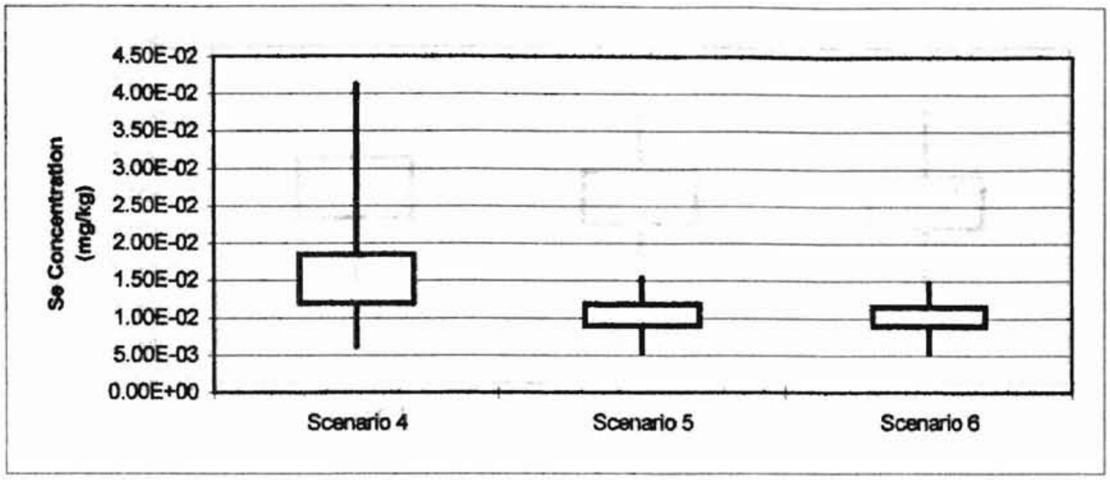


Figure 47. Probability distribution comparison for terrestrial plants compartment.

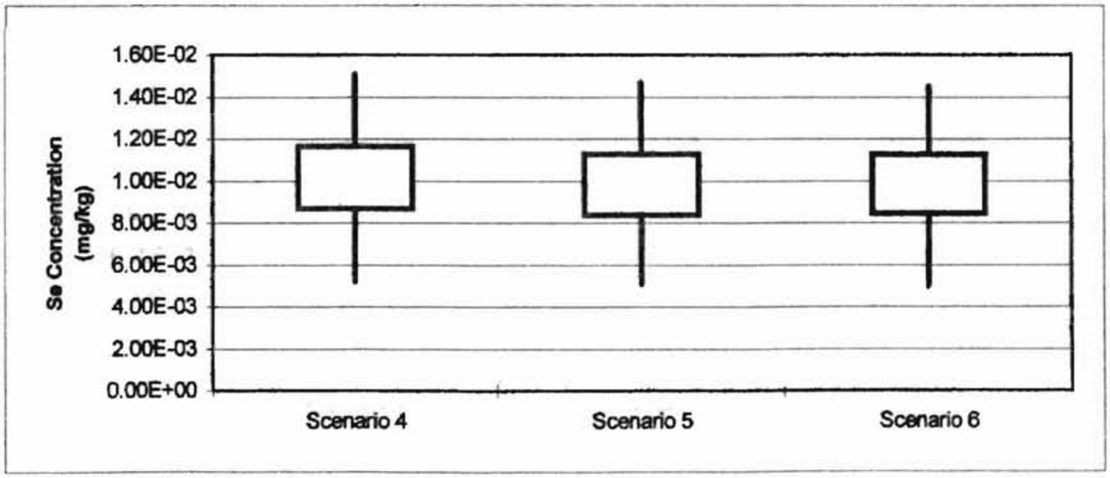


Figure 48. Probability distribution comparison for carnivorous fish compartment.

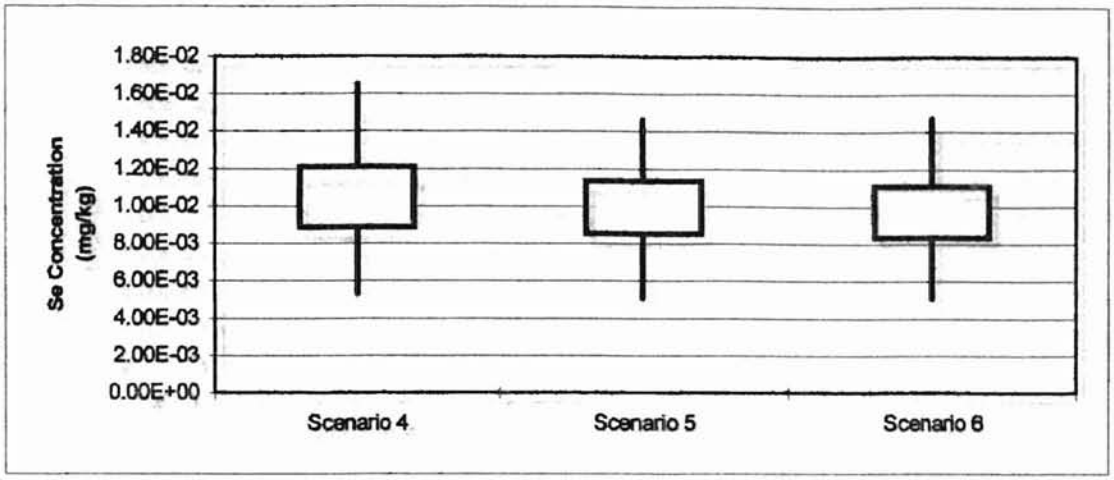


Figure 49. Probability distribution comparison for herbivorous fish compartment.

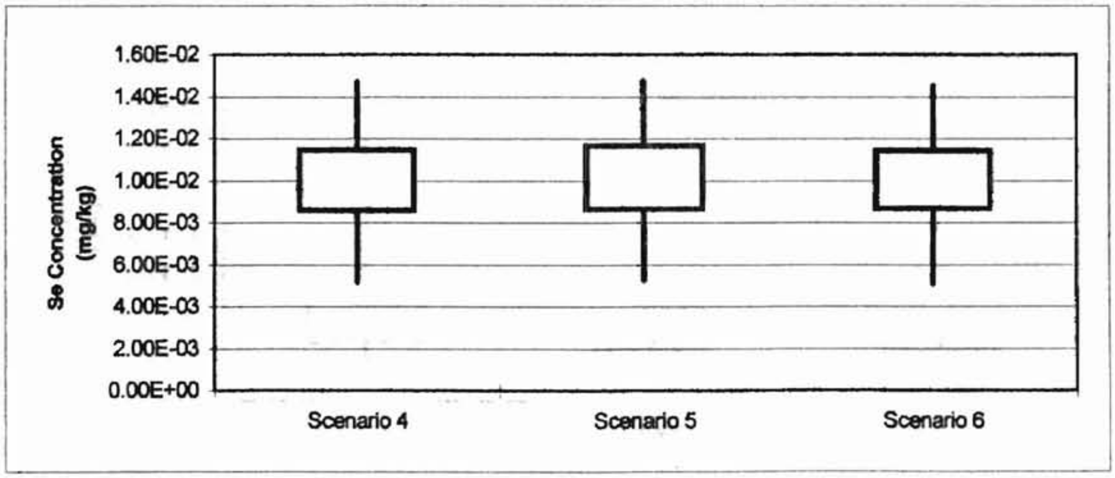


Figure 50. Probability distribution comparison for aquatic carnivorous invertebrates compartment.

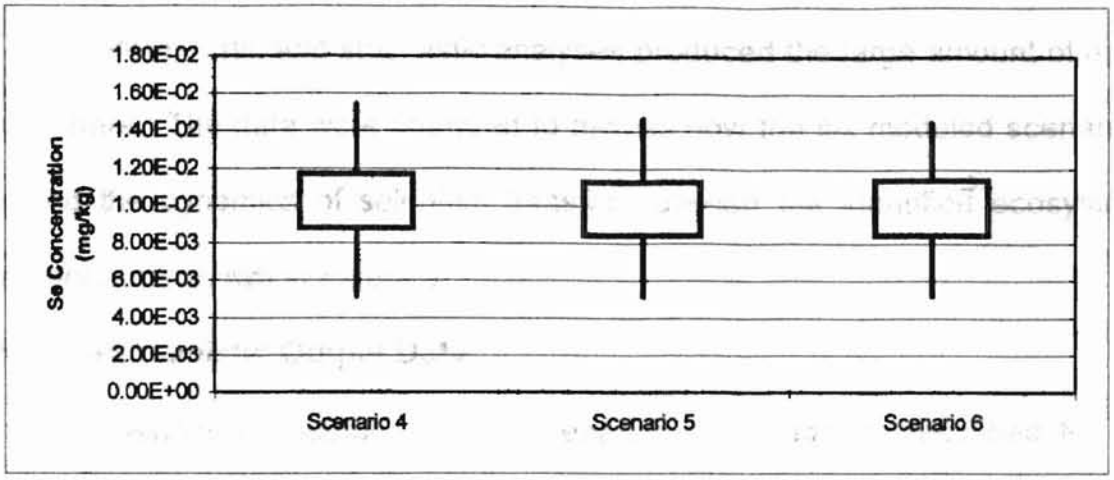


Figure 51. Probability distribution comparison for aquatic herbivorous invertebrates compartment.

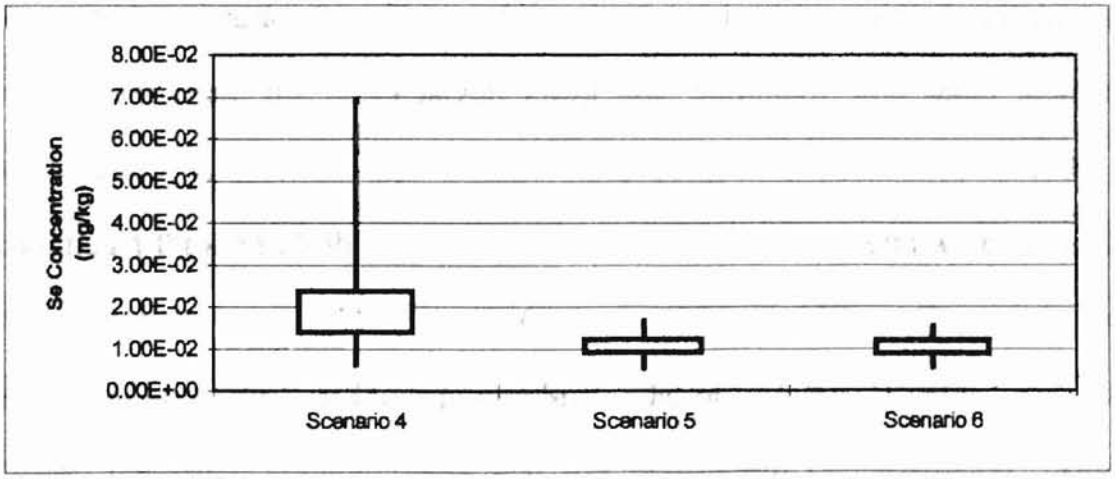


Figure 52. Probability distribution comparison for aquatic plants compartment.

4. DISCUSSION

The deterministic and stochastic analyses produced the large amount of data shown here. The data were analyzed to assess how the six modeled scenarios affected the dynamics of selenium transfer between the identified ecosystem compartments shown in Figure 3.

4.1 Deterministic Output Data

The deterministic output data for scenarios 1 through 3, described for all compartments in Figures 5 through 28, are represented by a fairly sigmoid curve which begins at the initial compartmental contaminant concentration (C_o) and then asymptotes toward 100% of the endpoint concentration (C_e). These data were used to compare the effects of the time required to reach C_e within each compartment under the successively lower soil, sediment, and water selenium concentrations suggested by CH2M Hill (1986). Under ASSUMPTION A (scenarios 1 through 3), the initial biotic selenium concentrations were set at the levels reported by CH2M Hill (1986) and USBR (1990). The underlying assumption here was that the reported levels did not reflect an equilibrium state between the biotic compartments and the ecosystem contamination. Under ASSUMPTION B (scenarios 4 through 6), a equilibrium state was assumed and the biotic C_e concentrations were set at the levels reported by CH2M Hill (1986) and USBR (1990).

As expected, the time required to reach the endpoint concentration increased for all compartments as the concentration within the three abiotic compartments decreased. However, appreciable differences were not realized in the top carnivore, waterfowl, carnivorous mammals, and aquatic carnivorous invertebrates compartments (see Figures 5, 6, 7, 12, and 14) under ASSUMPTION A criteria. A slight decrease in the time to C_e was calculated under ASSUMPTION A criteria for the terrestrial carnivorous and herbivorous invertebrates (Figures 9 and 10), herbivorous fish (Figure 13), and the aquatic herbivorous invertebrates (Figure 15) compartments. The most significant decreases for scenarios 1 through 3 were seen in the herbivorous mammals, terrestrial plants, and aquatic plants compartments as shown in Figures 8, 11, and 16 respectively. The ASSUMPTION B criteria results returned for scenarios 4 through 6 (Figures 17 through 28) provided the most striking stratification of time to C_e for all twelve biotic compartments.

In each case, the lower trophic levels generally appeared to be much more responsive to changes in the abiotic contaminant concentration than were the higher levels of the food web. Since increasingly higher trophic levels logically accumulate contaminant from increasingly more sources than the lower levels, this result would appear to be a plausible representation of natural food web dynamics.

4.2 Stochastic Output Data

As previously described, the stochastic analysis was twofold. First, a rank order correlation was performed which related model output results to the input parameters. This portion of the stochastic analysis was done in order to measure the relative sensitivity the input parameters had on the final output. Secondly, the model was executed once for each of the five described scenarios in order to generate probability distribution functions for comparison of the various selenium contaminant levels at 1986 levels and the ONSITE-1 and ONSITE-2 cleanup goals.

4.2.1 Sensitivity of Outputs to Inputs

A rank order correlation analysis was performed for each compartment in an attempt to better understand the relative sensitivity each uncertain input variable had on the final output results. Not surprising, the initial contaminant concentration (C_o) had nearly a perfect positive correlation on the output results for all twelve biotic compartments. Unexpected however, was that this parameter was the only variable resulting in a strong correlation.

4.2.2 Stochastic Output Result Ranges and Probability Distributions

The Latin Hypercube analysis generated ranges and probability density functions (pfds) for each compartmental contaminant concentration at the initial time step (t = 1). As before, the model was run once for each of the six scenarios. Summary results for scenarios 1 through 6 are presented in Tables 44 though 49. The intraquartile range and maximum and minimum values returned for each compartment under the six contaminant scenarios are compared in the box and whisker diagrams of Figures 29 through 52. Unlike the deterministic analysis, reducing the abiotic selenium concentrations did not universally reduce the modeled selenium concentration in all biotic compartments under scenarios 1 through 6. In fact, for several compartments, the model returned high maximum values for scenarios 2 and 3 (ASSUMPTION A criteria) and scenarios 5 and 6 (ASSUMPTION B criteria) than for scenarios 1 and 4. The terrestrial and aquatic plants were the only two compartments which showed a significant downward shift in probability range (see Figures 35, 40, 47, and 52) under both assumption criteria. These two compartments represent the lowest trophic levels and could be assumed to reflect a decrease in soil, sediment, and water selenium concentrations prior to the other compartments.

5. SUMMARY and CONCLUSIONS

Ecological risk assessment is a broad and complicated endeavor which, as described by Norton *et al.* (1992), requires analysts to measure the probability of ecological damage due to stressor contamination. In order to complete projects within generally acceptable timeframes and in an economically feasible manner, researchers must often times reduce complicated ecosystem interactions to simplified mathematical expressions (i.e., models). Unfortunately, no model will ever fully describe ecological interactions and very few input data sets are complete. For these reasons, risk assessors are faced with uncertainties surrounding not only the models chosen, but the input data used to calculate the output results. As such, the final results of an analysis must be interpreted with an understanding of the relative uncertainty inherent to the chosen model and input data. Stochastic modeling techniques can aid researches in managing input parameter uncertainties. Selection of the proper model for a specific site or contaminant should be done very carefully so to reduce model uncertainties.

The model chosen for this work lent itself well to the compartment-based approach as well as incorporating first-order kinetics and equilibrium partitioning components into a single term. The modeled results under the six scenarios appear to make sense ecologically. For the deterministic assessment, as the soil, sediment, and water selenium concentrations were reduced, the model returned decreased selenium concentrations in the twelve biotic compartments. As expected, decreases were most notable in the lower trophic levels which are more intimately related to the three abiotic elements of the modeled system. The stochastic analysis did not provide as clear a relationship between decreased abiotic selenium concentrations and the output data as did the point estimate approach. However, the two lowest trophic levels (terrestrial and aquatic plants) did show a marked decrease in compartmental selenium concentration as the abiotic compartments were reduced.

The results of the deterministic and stochastic analyses suggest that the ONSITE-1 and ONSITE-2 cleanup alternatives proposed by CH2M Hill (1986) would not likely benefit the current resident populations which are already "loaded" with selenium. However, future generations would enjoy a much reduced level of risk.

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APPENDIX A – BESTFIT (1998) CURVE FITTING SUMMARY STATISTICS FOR Se WATER CONTAMINANT CONCENTRATION AT KESTERSON RESERVOIR

	Input Distribution	Normal	Weibull	Beta	Rayleigh	Logistic	Gamma	Erlang	PearsonVI	Lognorm	Lognorm2
Parameter 1		0.228	1.732	2.168	0.185	0.228	2.032	2.000	3.087	0.270	-1.744
Parameter 2		0.129	0.253	7.417		0.070	0.112	0.114	2.547	0.318	0.933
Parameter 3									0.112		
Minimum	0.002			0.002							
Maximum	0.540										
Mean	0.228	0.228	0.228	0.228	0.232	0.228	0.228	0.228	0.289	0.270	0.270
Mode	0.244	0.228	0.154	0.158	0.185	0.228	0.116	0.114	0.094	0.073	0.073
Median	0.230	0.228	0.205	0.208	0.218	0.228	0.192	0.191	0.185	0.175	0.175
Standard Deviation	0.129	0.129	0.134	0.129	0.121	0.128	0.160	0.161	0.461	0.318	0.318
Variance	0.017	0.017	0.018	0.017	0.015	0.016	0.026	0.026	0.212	0.101	0.101
Skewness	0.399	0.000	0.777	0.736	0.631	0.000	1.403	1.414	3.658	5.167	5.167
Kurtosis	2.422	3.000	3.354	4.024	3.245	4.200	5.953	6.000	20.868	73.760	73.760
Histogram											
Minimum	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Maximum	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.540
P1	5.000	3.675	5.355	4.050	3.284	2.942	6.584	6.779	5.136	9.038	9.038
P2	10.000	8.438	10.248	10.110	8.607	8.578	12.058	12.100	14.381	14.724	14.724
P3	10.000	9.461	12.120	12.453	11.952	9.391	12.519	12.458	13.067	11.862	11.862
P4	10.000	11.674	11.840	12.211	12.681	12.980	10.921	10.834	9.806	8.790	8.790
P5	12.000	12.091	10.229	10.541	11.733	13.782	8.741	8.666	7.079	6.454	6.454
P6	10.000	10.512	8.043	8.304	9.342	11.002	6.647	6.599	5.121	4.786	4.786
P7	7.000	7.670	5.844	6.058	6.611	7.001	4.884	4.860	3.758	3.606	3.606
P8	5.000	4.698	3.980	4.112	4.197	3.641	3.502	3.495	2.807	2.757	2.757
P9	1.000	2.415	2.519	2.594	2.406	1.941	2.466	2.469	2.134	2.139	2.139
P10	3.000	1.042	1.510	1.511	1.249	0.940	1.711	1.721	1.651	1.681	1.661
Chi-Square											
Test Value		7.333	4.355	4.440	5.590	11.310	7.622	7.830	16.349	20.885	20.885
Confidence		>0.6	>0.88	>0.88	>0.78	>0.25	>0.57	>0.55	>0.05	>0.01	>0.01
Rank		4	1	2	3	8	5	6	9	13	12
Kolmogorov-Smirnov											
Test Value		0.098	0.108	0.097	0.093	0.120	0.125	0.127	0.144	0.166	0.166
Confidence		>0.05	>0.025	>0.15 *	>0.15 *	>0.15 *	>0.15 *	>0.15 *	>0.05 *	>0.025 *	>0.025 *
Rank		2	4	3	1	6	7	8	9	10	11
Anderson-Darling											
Test Value		0.457	0.757	1.030	1.056	0.815	1.386	1.416	2.632	3.288	3.288
Confidence		>0.15	>0.025	>0.15 *	>0.15 *	>0.15 *	>0.15 *	>0.15 *	>0.025 *	>0.01 *	>0.01 *
Rank		1	2	4	5	3	7	8	9	10	11
Confidence											
Chi-Square											
Adjusted Value		7.333	4.355	4.440	5.590	11.310	7.622	7.830	16.349	20.885	20.885
Critical Value @ 0.750		5.899	5.899	5.899	5.899	5.899	5.899	5.899	5.899	5.899	5.899
Critical Value @ 0.500		8.343	8.343	8.343	8.343	8.343	8.343	8.343	8.343	8.343	8.343
Critical Value @ 0.250		11.389	11.389	11.389	11.389	11.389	11.389	11.389	11.389	11.389	11.389
Critical Value @ 0.100		14.684	14.684	14.684	14.684	14.684	14.684	14.684	14.684	14.684	14.684
Critical Value @ 0.050		16.919	16.919	16.919	16.919	16.919	16.919	16.919	16.919	16.919	16.919
Critical Value @ 0.025		19.023	19.023	19.023	19.023	19.023	19.023	19.023	19.023	19.023	19.023
Critical Value @ 0.010		21.666	21.666	21.666	21.666	21.666	21.666	21.666	21.666	21.666	21.666
Kolmogorov-Smirnov											
Adjusted Value		0.825	0.881	0.836	0.806	1.038	1.084	1.098	1.246	1.439	1.439
Critical Value @ 0.150		0.774		1.138	1.138	1.138	1.138	1.138	1.138	1.138	1.138
Critical Value @ 0.100		0.819	0.803	1.224	1.224	1.224	1.224	1.224	1.224	1.224	1.224
Critical Value @ 0.050		0.895	0.874	1.358	1.358	1.358	1.358	1.358	1.358	1.358	1.358
Critical Value @ 0.025		0.955	0.939	1.480	1.480	1.480	1.480	1.480	1.480	1.480	1.480
Critical Value @ 0.010		1.035	1.007	1.628	1.628	1.628	1.628	1.628	1.626	1.628	1.626
Anderson-Darling											
Adjusted Value		0.479	0.758	1.030	1.068	0.815	1.386	1.416	2.632	3.288	3.288
Critical Value @ 0.250			0.474								
Critical Value @ 0.150		0.576		1.610	1.610	1.610	1.610	1.610	1.610	1.610	1.610
Critical Value @ 0.100		0.656	0.637	1.933	1.933	1.933	1.933	1.933	1.933	1.933	1.933
Critical Value @ 0.050		0.787	0.757	2.492	2.492	2.492	2.492	2.492	2.492	2.492	2.492
Critical Value @ 0.025		0.918	0.877	3.070	3.070	3.070	3.070	3.070	3.070	3.070	3.070
Critical Value @ 0.010		1.092	1.038	3.857	3.857	3.857	3.857	3.857	3.857	3.857	3.857

APPENDIX B – VISUAL BASIC (MACRO) CODE USED FOR MODEL AUTOMATION PROCESSES

```
'
' RUN MODEL
' Macro recorded 2/22/99 by Michael L. Thayer
'
'
Sub Run_Model()
   Application.ScreenUpdating = False
   Sheets("RAW").Select
'Clear previous TOP CARNIVORE results
   Range("B9").Select
   Range(ActiveCell, ActiveCell.End(xlDown)).Select
   Selection.Borders(xlLeft).LineStyle = xlNone
   Selection.Borders(xlRight).LineStyle = xlNone
   Selection.Borders(xlTop).LineStyle = xlNone
   Selection.Borders(xlBottom).LineStyle = xlNone
   Selection.BorderAround LineStyle:=xlNone
   Selection.ClearContents
   Range("C9").Select
   Range(ActiveCell, ActiveCell.End(xlDown)).Select
   Selection.Borders(xlLeft).LineStyle = xlNone
   Selection.Borders(xlRight).LineStyle = xlNone
   Selection.Borders(xlTop).LineStyle = xlNone
   Selection.Borders(xlBottom).LineStyle = xlNone
   Selection.BorderAround LineStyle:=xlNone
   Selection.ClearContents
   Range("D9").Select
   Range(ActiveCell, ActiveCell.End(xlDown)).Select
   Selection.Borders(xlLeft).LineStyle = xlNone
   Selection.Borders(xlRight).LineStyle = xlNone
   Selection.Borders(xlTop).LineStyle = xlNone
   Selection.Borders(xlBottom).LineStyle = xlNone
   Selection.BorderAround LineStyle:=xlNone
   Selection.ClearContents
'Clear previous WATERFOWL results
   Range("F9").Select
   Range(ActiveCell, ActiveCell.End(xlDown)).Select
   Selection.Borders(xlLeft).LineStyle = xlNone
   Selection.Borders(xlRight).LineStyle = xlNone
   Selection.Borders(xlTop).LineStyle = xlNone
   Selection.Borders(xlBottom).LineStyle = xlNone
   Selection.BorderAround LineStyle:=xlNone
   Selection.ClearContents
```

```
    Range("G9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("H9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous CARNIVOROUS MAMMALS results
    Range("J9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("K9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("L9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous HERBIVOROUS MAMMALS results
    Range("N9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
```

```
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("O9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("P9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous TERRESTRIAL CARNIVOROUS INVERTEBRATES results
    Range("R9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("S9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("T9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
```

```
    Selection.ClearContents
'Clear previous TERRESTRIAL HERBIVOROUS INVERTEBRATES results
    Range("V9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("W9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("X9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous TERRESTRIAL PLANTS results
    Range("Z9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AA9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AB9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
```

```
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous CARNIVOROUS FISH results
    Range("AD9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AE9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AF9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous HERBIVOROUS FISH results
    Range("AH9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AI9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
```

```
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AJ9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous AQUATIC CARNIVOROUS INVERTEBRATES results
    Range("AL9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AM9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AN9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous AQUATIC HERBIVOROUS INVERTEBRATES results
    Range("AP9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
```

```
    Range("AQ9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AR9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Clear previous AQUATIC PLANTS results
    Range("AT9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AU9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
    Range("AV9").Select
    Range(ActiveCell, ActiveCell.End(xlDown)).Select
    Selection.Borders(xlLeft).LineStyle = xlNone
    Selection.Borders(xlRight).LineStyle = xlNone
    Selection.Borders(xlTop).LineStyle = xlNone
    Selection.Borders(xlBottom).LineStyle = xlNone
    Selection.BorderAround LineStyle:=xlNone
    Selection.ClearContents
'Calculate new results for TOP CARNIVORE
    Range(Cells(8, 2), Cells(8, 4)).Select
    Selection.Copy
    Range(Cells(8 + 1, 2), Cells(8 + (Cells(4, 4).Value - 1), 4)).Select
```

```
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 4).Value - 1), 2), Cells(8 + (Cells(4, 4).Value - 1),
4)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for WATERFOWL
   Range(Cells(8, 6), Cells(8, 8)).Select
   Selection.Copy
   Range(Cells(8 + 1, 6), Cells(8 + (Cells(4, 8).Value - 1), 8)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 8).Value - 1), 6), Cells(8 + (Cells(4, 8).Value - 1),
8)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for CARNIVOROUS MAMMALS
   Range(Cells(8, 10), Cells(8, 12)).Select
   Selection.Copy
   Range(Cells(8 + 1, 10), Cells(8 + (Cells(4, 12).Value - 1), 12)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 12).Value - 1), 10), Cells(8 + (Cells(4, 12).Value -
1), 12)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for HERBIVOROUS MAMMALS
   Range(Cells(8, 14), Cells(8, 16)).Select
   Selection.Copy
   Range(Cells(8 + 1, 14), Cells(8 + (Cells(4, 16).Value - 1), 16)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 16).Value - 1), 14), Cells(8 + (Cells(4, 16).Value -
1), 16)).Select
   With Selection.Borders(xlBottom)
```

```
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for TERRESTRIAL CARNIVOROUS INVERTEBRATES
   Range(Cells(8, 18), Cells(8, 20)).Select
   Selection.Copy
   Range(Cells(8 + 1, 18), Cells(8 + (Cells(4, 20).Value - 1), 20)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 20).Value - 1), 18), Cells(8 + (Cells(4, 20).Value -
1), 20)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for TERRESTRIAL HERBIVOROUS INVERTEBRATES
   Range(Cells(8, 22), Cells(8, 24)).Select
   Selection.Copy
   Range(Cells(8 + 1, 22), Cells(8 + (Cells(4, 24).Value - 1), 24)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 24).Value - 1), 22), Cells(8 + (Cells(4, 24).Value -
1), 24)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for TERRESTRIAL PLANTS
   Range(Cells(8, 26), Cells(8, 28)).Select
   Selection.Copy
   Range(Cells(8 + 1, 26), Cells(8 + (Cells(4, 28).Value - 1), 28)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 28).Value - 1), 26), Cells(8 + (Cells(4, 28).Value -
1), 28)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for CARNIVOROUS FISH
   Range(Cells(8, 30), Cells(8, 32)).Select
   Selection.Copy
```

```
  Range(Cells(8 + 1, 30), Cells(8 + (Cells(4, 32).Value - 1), 32)).Select
  ActiveSheet.Paste
  Application.CutCopyMode = False
  'Place bold line at bottom of Raw Output Results Table
  Range(Cells(8 + (Cells(4, 32).Value - 1), 30), Cells(8 + (Cells(4, 32).Value -
1), 32)).Select
  With Selection.Borders(xlBottom)
    .Weight = xlMedium
    .ColorIndex = xlAutomatic
  End With
'Calculate new results for HERBIVOROUS FISH
  Range(Cells(8, 34), Cells(8, 36)).Select
  Selection.Copy
  Range(Cells(8 + 1, 34), Cells(8 + (Cells(4, 36).Value - 1), 36)).Select
  ActiveSheet.Paste
  Application.CutCopyMode = False
  'Place bold line at bottom of Raw Output Results Table
  Range(Cells(8 + (Cells(4, 36).Value - 1), 34), Cells(8 + (Cells(4, 36).Value -
1), 36)).Select
  With Selection.Borders(xlBottom)
    .Weight = xlMedium
    .ColorIndex = xlAutomatic
  End With
'Calculate new results for AQUATIC CARNIVOROUS INVERTEBRATES
  Range(Cells(8, 38), Cells(8, 40)).Select
  Selection.Copy
  Range(Cells(8 + 1, 38), Cells(8 + (Cells(4, 40).Value - 1), 40)).Select
  ActiveSheet.Paste
  Application.CutCopyMode = False
  'Place bold line at bottom of Raw Output Results Table
  Range(Cells(8 + (Cells(4, 40).Value - 1), 38), Cells(8 + (Cells(4, 40).Value -
1), 40)).Select
  With Selection.Borders(xlBottom)
    .Weight = xlMedium
    .ColorIndex = xlAutomatic
  End With
'Calculate new results for AQUATIC HERBIVOROUS INVERTEBRATES
  Range(Cells(8, 42), Cells(8, 44)).Select
  Selection.Copy
  Range(Cells(8 + 1, 42), Cells(8 + (Cells(4, 44).Value - 1), 44)).Select
  ActiveSheet.Paste
  Application.CutCopyMode = False
  'Place bold line at bottom of Raw Output Results Table
  Range(Cells(8 + (Cells(4, 44).Value - 1), 42), Cells(8 + (Cells(4, 44).Value -
1), 44)).Select
```

```
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Calculate new results for AQUATIC PLANTS
   Range(Cells(8, 46), Cells(8, 48)).Select
   Selection.Copy
   Range(Cells(8 + 1, 46), Cells(8 + (Cells(4, 48).Value - 1), 48)).Select
   ActiveSheet.Paste
   Application.CutCopyMode = False
   'Place bold line at bottom of Raw Output Results Table
   Range(Cells(8 + (Cells(4, 48).Value - 1), 46), Cells(8 + (Cells(4, 48).Value -
1), 48)).Select
   With Selection.Borders(xlBottom)
      .Weight = xlMedium
      .ColorIndex = xlAutomatic
   End With
'Return to cell A1 of RAW DATA OUTPUT worksheet
   Cells(1, 1).Select
'Return to cell A1 of OUTPUTS worksheet
   Sheets("OUTPUTS").Select
   Cells(1, 1).Select
End Sub
```

APPENDIX C – STOCHASTIC MODEL SIMULATION SUMMARY STATISTICS UNDER SCENARIO 1 CONDITIONS

Simulation Results for INITIAL-I.xls

Iterations	1,400
Simulations	1
# Input Variables	141
# Output Variables	12
Sampling Type	Latin hypercube
Runtime	00:01:28

Summary Statistics

	TOP CARNIVORE	WATERFOWL	CARNIVOROUS MAMMALS	HERBIVOROUS MAMMALS	TERRESTRIAL CARNIVOROUS INVERTEBRATES	TERRESTRIAL HERBIVOROUS INVERTEBRATES	TERRESTRIAL PLANTS	CARNIVOROUS FISH	HERBIVOROUS FISH	AQUATIC CARNIVOROUS INVERTEBRATES	AQUATIC HERBIVOROUS INVERTEBRATES	AQUATIC PLANTS
Minimum =	2.292	3.245	1.548	1.193	2.821	0.861	0.729	6.799	7.520	-76.376	28.255	0.822
Maximum =	130.819	61.742	131.036	128.599	82.460	63.628	123.098	353.310	302.259	187.982	287.208	166.447
Mean =	54.211	20.698	54.478	50.275	31.939	20.887	39.239	157.508	136.395	78.741	136.381	45.433
Std Deviation =	28.725	10.766	28.578	27.543	18.781	10.802	23.162	51.546	49.625	30.321	42.888	27.217
Variance =	825.108	115.909	816.717	758.626	352.720	116.686	536.480	2,657.005	2,462.624	919.341	1,839.411	740.767
Skewness =	0.348	0.542	0.129	0.231	0.554	0.407	0.438	-0.225	-0.225	-0.148	0.046	0.800
Kurtosis =	2.176	2.613	2.089	2.118	2.378	2.344	2.411	3.004	2.704	4.714	2.618	3.100
Errors Calculated =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mode =	58.287	9.234	64.422	27.647	9.531	11.727	12.630	182.058	166.276	85.628	141.083	21.887
5% Perc =	12.347	6.387	11.110	10.037	7.791	5.461	8.581	62.784	46.788	38.300	61.873	7.834
10% Perc =	16.715	7.735	15.747	14.091	9.611	7.703	10.282	84.969	66.492	44.334	80.882	11.944
15% Perc =	21.279	9.104	20.501	18.190	11.580	9.418	13.729	103.576	82.501	50.356	91.589	15.591
20% Perc =	25.421	10.295	26.347	22.388	13.541	10.757	16.624	115.822	96.546	54.794	98.972	19.676
25% Perc =	29.494	11.720	30.327	27.386	15.790	12.008	18.709	128.000	108.889	58.900	106.977	23.321
30% Perc =	34.427	12.983	35.416	31.671	18.309	13.282	22.766	133.431	115.913	64.185	113.127	26.882
35% Perc =	38.338	14.486	40.436	36.653	20.917	14.616	25.832	141.691	124.725	67.804	118.795	30.728
40% Perc =	44.280	16.013	44.448	40.839	23.321	16.518	29.106	148.337	132.809	71.586	124.081	34.028
45% Perc =	48.542	17.388	49.815	44.672	26.118	17.875	32.573	154.716	136.348	74.911	128.880	37.888
50% Perc =	52.721	18.984	53.388	48.083	28.468	19.888	37.241	160.843	143.945	79.104	136.319	41.911
55% Perc =	57.058	20.655	58.744	52.635	31.450	21.326	40.487	166.941	149.891	82.834	141.381	46.388
60% Perc =	61.671	22.405	64.419	57.541	34.639	23.135	44.082	172.744	155.458	86.980	146.888	50.427
65% Perc =	65.944	24.419	68.270	62.019	38.191	24.729	48.484	179.214	163.054	89.788	152.800	55.034
70% Perc =	71.058	26.391	72.767	67.100	41.671	26.422	52.477	186.317	168.086	93.707	158.887	60.404
75% Perc =	76.224	28.303	77.157	71.815	45.458	28.414	56.663	193.076	173.841	97.880	165.793	65.458
80% Perc =	81.605	30.532	81.590	76.229	49.920	31.165	61.268	200.077	180.546	103.600	174.482	69.488
85% Perc =	86.398	33.348	87.142	81.207	54.184	33.882	65.884	208.580	188.030	110.685	183.837	75.882
90% Perc =	93.849	36.192	91.278	86.985	59.447	36.451	71.383	219.671	198.454	119.084	193.680	81.716
95% Perc =	103.794	40.138	101.168	97.503	67.614	40.427	78.717	235.495	214.381	128.578	209.833	93.774

APPENDIX D – STOCHASTIC MODEL SIMULATION SUMMARY STATISTICS UNDER SCENARIO 2 CONDITIONS

Simulation Results for ONSITE-1-I

Iterations	1,300
Simulations	1
# Input Variables	136
# Output Variables	12
Sampling Type	Latin Hypercube
Runtime	00:01:28

Summary Statistics

	TOP CARNIVORE	WATERFOWL	CARNIVOROUS MAMMALS	HERBIVOROUS MAMMALS	TERRESTRIAL CARNIVOROUS INVERTEBRATES	TERRESTRIAL HERBIVOROUS INVERTEBRATES	TERRESTRIAL PLANTS	CARNIVOROUS FISH	HERBIVOROUS FISH	AQUATIC CARNIVOROUS INVERTEBRATES	AQUATIC HERBIVOROUS INVERTEBRATES	AQUATIC PLANTS
Minimum =	-2.828	2.214	1.241	1.031	2.643	0.846	0.862	10.631	11.045	-110.727	30.862	0.483
Maximum =	132.558	58.154	131.546	117.822	83.084	47.674	91.002	298.913	311.224	165.346	288.697	81.906
Mean =	55.840	20.482	53.004	49.626	32.405	19.086	29.185	154.854	136.089	81.089	133.190	28.402
Std Deviation =	27.927	10.460	28.086	27.950	18.534	10.019	18.629	50.180	47.996	31.382	43.887	19.041
Variance =	779.913	109.211	787.810	781.204	343.510	100.377	347.088	2,517.985	2,303.644	984.840	1,926.490	362.580
Skewness =	0.127	0.541	0.160	0.307	0.638	0.486	0.517	-0.237	-0.087	-0.314	0.076	0.548
Kurtosis =	2.158	2.623	2.108	2.101	2.419	2.420	2.330	3.038	3.144	4.730	2.548	2.391
Errors Calculated =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mode =	80.689	13.175	38.943	73.819	8.154	22.080	8.745	148.426	191.859	65.023	150.484	6.869
5% Perc =	13.368	6.445	10.786	10.299	8.015	5.287	4.750	63.868	40.583	33.241	61.827	4.214
10% Perc =	19.210	7.851	15.319	13.154	10.218	7.379	6.677	88.650	69.896	42.830	74.014	6.774
15% Perc =	24.178	9.227	20.150	17.161	12.583	8.459	9.248	103.743	84.079	50.053	85.125	8.980
20% Perc =	29.578	10.420	24.209	21.588	14.405	9.771	11.085	114.127	95.557	57.314	92.457	10.820
25% Perc =	34.833	11.548	28.234	26.234	16.627	10.888	13.322	123.888	106.928	61.304	101.121	13.114
30% Perc =	39.256	13.086	34.216	30.680	19.067	12.188	15.536	131.738	113.863	65.944	109.584	15.741
35% Perc =	43.081	14.482	38.683	34.603	21.910	13.630	17.801	139.731	120.195	68.979	115.760	18.384
40% Perc =	47.275	15.983	43.324	38.351	24.081	14.881	20.477	145.087	128.375	72.624	121.310	21.088
45% Perc =	50.786	17.632	48.145	42.169	26.928	16.191	23.284	150.710	132.820	76.758	128.864	23.679
50% Perc =	54.751	19.362	52.445	46.331	29.545	17.308	26.139	155.826	140.297	80.720	132.095	26.169
55% Perc =	58.737	20.894	57.458	50.281	32.612	19.236	29.319	162.805	145.182	84.603	136.885	28.730
60% Perc =	64.500	22.391	61.804	55.762	35.081	20.678	32.614	169.099	150.513	87.440	145.048	32.096
65% Perc =	68.688	24.043	65.629	61.288	39.253	22.170	35.892	175.697	155.804	91.427	150.732	34.981
70% Perc =	74.291	25.679	69.813	66.001	41.925	24.008	38.113	182.412	160.786	95.810	155.745	38.307
75% Perc =	78.928	27.338	74.678	71.546	45.487	25.933	42.490	189.586	167.887	101.541	164.221	42.886
80% Perc =	83.013	29.736	78.797	76.841	49.988	28.385	46.881	197.234	173.757	106.726	171.670	47.000
85% Perc =	88.115	31.949	85.070	82.738	54.271	30.882	51.378	208.416	182.343	112.666	180.829	51.774
90% Perc =	95.113	35.528	91.308	89.546	58.988	33.913	57.279	216.657	192.112	119.854	191.786	57.957
95% Perc =	102.891	38.983	100.484	97.457	67.257	37.578	62.981	233.075	208.465	135.512	204.226	65.512

APPENDIX E – STOCHASTIC MODEL SIMULATION SUMMARY STATISTICS UNDER SCENARIO 3 CONDITIONS

Simulation Results for ONSITE-3-I

Iterations	1,100
Simulations	1
# Input Variables	138
# Output Variables	12
Sampling Type	Latin hypercube
Runtime	00:01:36

Summary Statistics

	TOP CARNIVORE	WATERFOWL	CARNIVOROUS MAMMALS	HERBIVOROUS MAMMALS	TERRESTRIAL CARNIVOROUS INVERTEBRATES	TERRESTRIAL HERBIVOROUS INVERTEBRATES	TERRESTRIAL PLANTS	CARNIVOROUS FISH	HERBIVOROUS FISH	AQUATIC CARNIVOROUS INVERTEBRATES	AQUATIC HERBIVOROUS INVERTEBRATES	AQUATIC PLANTS
Minimum =	2.502	2.612	1.528	1.200	2.463	1.328	0.367	14.684	8.620	-56.719	27.195	0.669
Maximum =	148.328	55.611	130.581	117.849	81.197	69.782	79.676	302.897	305.181	176.611	282.283	80.021
Mean =	56.601	20.088	64.178	60.907	31.542	19.453	23.009	156.321	138.741	80.135	132.398	29.173
Std Deviation =	28.468	10.596	28.353	28.571	18.459	10.341	18.549	49.945	49.946	30.048	43.934	18.600
Variance =	810.409	112.281	803.920	816.277	340.749	106.927	344.082	2,494.488	2,494.559	902.857	1,930.180	345.958
Skewness =	0.119	0.680	0.148	0.228	0.541	0.494	0.573	-0.265	-0.122	-0.079	-0.109	0.591
Kurtosis =	2.205	2.782	2.024	2.021	2.400	2.649	2.430	2.800	2.922	3.816	2.436	2.386
Errors Calculated =	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mode =	74.137	7.431	47.388	16.353	27.929	10.310	28.489	173.808	143.578	74.081	150.171	11.037
5% Perc =	11.694	5.819	12.003	8.760	7.698	4.667	5.020	65.581	48.992	32.879	55.204	4.661
10% Perc =	16.634	7.478	18.401	13.593	9.389	6.959	7.235	85.987	64.510	43.071	72.045	7.441
15% Perc =	20.888	8.083	20.625	17.721	11.720	8.578	8.327	98.887	83.254	51.467	83.885	8.473
20% Perc =	27.476	10.178	25.443	21.738	13.505	9.754	11.069	110.250	92.699	58.250	91.197	11.132
25% Perc =	33.350	11.588	29.804	25.442	15.621	10.718	13.277	121.438	102.448	60.543	99.917	13.029
30% Perc =	37.788	12.887	34.023	29.884	19.108	12.131	15.481	132.789	113.831	64.710	108.821	15.579
35% Perc =	42.177	14.383	40.474	35.218	20.341	13.846	17.908	140.881	121.399	69.324	116.608	18.645
40% Perc =	47.353	15.559	44.670	38.382	23.141	15.228	20.882	147.837	128.620	72.143	121.712	20.818
45% Perc =	52.108	16.803	48.643	44.601	25.982	16.829	23.629	153.429	134.893	75.681	127.546	22.893
50% Perc =	58.134	18.250	52.739	49.487	28.973	18.378	25.934	159.494	141.713	78.869	138.083	26.025
55% Perc =	60.392	19.661	58.108	54.322	31.888	19.900	28.704	165.208	147.514	83.322	140.358	28.898
60% Perc =	64.324	21.088	62.516	59.288	34.281	21.321	31.139	171.348	152.527	87.548	146.661	32.025
65% Perc =	68.570	23.223	68.801	65.085	38.225	23.149	34.938	177.290	157.942	91.530	151.921	34.748
70% Perc =	73.228	25.422	71.263	68.731	41.014	24.553	38.754	183.286	164.442	94.812	157.832	38.625
75% Perc =	76.679	27.707	76.659	72.748	44.173	26.613	42.788	190.341	170.959	97.914	164.488	42.185
80% Perc =	81.398	29.388	81.600	77.530	48.302	28.514	48.712	197.518	177.138	102.888	173.301	48.479
85% Perc =	87.068	32.011	88.317	83.485	52.940	31.836	50.538	208.801	184.201	109.231	180.639	51.982
90% Perc =	93.800	35.482	94.095	91.192	58.819	34.046	56.347	215.010	194.225	118.442	187.404	58.767
95% Perc =	103.038	39.324	100.512	98.675	66.982	37.304	64.715	229.709	211.709	135.117	200.773	64.016

APPENDIX F – STOCHASTIC MODEL SIMULATION SUMMARY STATISTICS UNDER SCENARIO 4 CONDITIONS

Simulation Results for INITIAL-1 1.xls

Iterations	1,400
Simulations	1
# Input Variables	141
# Output Variables	12
Sampling Type	Latin hypercube
Runtime	00:01:46

Summary Statistics

	TOP CARNIVORE	WATERFOWL	CARNIVOROUS MAMMALS	HERBIVOROUS MAMMALS	TERRESTRIAL CARNIVOROUS INVERTEBRATES	TERRESTRIAL HERBIVOROUS INVERTEBRATES	TERRESTRIAL PLANTS	CARNIVOROUS FISH	HERBIVOROUS FISH	AQUATIC CARNIVOROUS INVERTEBRATES	AQUATIC HERBIVOROUS INVERTEBRATES	AQUATIC PLANTS
Minimum =	5.36E-03	5.30E-03	5.30E-03	5.21E-03	6.23E-03	5.06E-03	6.09E-03	5.19E-03	5.28E-03	5.15E-03	5.12E-03	6.14E-03
Maximum =	1.54E-02	1.58E-02	1.69E-02	1.59E-02	1.49E-02	1.68E-02	4.13E-02	1.81E-02	1.65E-02	1.47E-02	1.54E-02	6.94E-02
Mean =	1.04E-02	1.03E-02	1.02E-02	1.03E-02	9.92E-03	1.04E-02	1.57E-02	1.01E-02	1.05E-02	9.98E-03	1.02E-02	1.96E-02
Std Deviation =	2.10E-03	2.10E-03	2.13E-03	2.17E-03	2.01E-03	2.20E-03	6.34E-03	2.13E-03	2.24E-03	1.98E-03	2.09E-03	8.31E-03
Variance =	4.41E-06	4.42E-06	4.53E-06	4.72E-06	4.04E-06	4.85E-06	2.85E-05	4.53E-06	5.04E-06	3.94E-06	4.36E-06	6.91E-05
Skewness =	-3.67E-03	3.79E-02	-1.60E-02	4.51E-02	2.18E-02	7.60E-02	1.06E+00	8.66E-02	1.46E-01	-5.10E-02	1.33E-02	1.44E+00
Kurtosis =	2.43E+00	2.50E+00	2.45E+00	2.38E+00	2.39E+00	2.52E+00	4.50E+00	2.39E+00	2.47E+00	2.36E+00	2.41E+00	6.42E+00
Errors Calculated =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mode =	1.08E-02	1.01E-02	9.44E-03	1.02E-02	1.01E-02	9.61E-03	1.18E-02	9.61E-03	1.15E-02	1.02E-02	9.02E-03	1.35E-02
5% Perc =	6.94E-03	6.63E-03	6.58E-03	6.66E-03	6.57E-03	6.72E-03	8.77E-03	6.61E-03	6.92E-03	6.58E-03	6.67E-03	8.79E-03
10% Perc =	7.50E-03	7.37E-03	7.31E-03	7.28E-03	7.17E-03	7.44E-03	9.69E-03	7.27E-03	7.63E-03	7.29E-03	7.36E-03	1.10E-02
15% Perc =	7.90E-03	7.92E-03	7.90E-03	7.87E-03	7.71E-03	8.10E-03	1.08E-02	7.78E-03	8.10E-03	7.73E-03	7.88E-03	1.20E-02
20% Perc =	8.50E-03	8.41E-03	8.38E-03	8.28E-03	8.15E-03	8.43E-03	1.13E-02	8.20E-03	8.46E-03	8.10E-03	8.38E-03	1.31E-02
25% Perc =	8.88E-03	8.74E-03	8.75E-03	8.71E-03	8.49E-03	8.82E-03	1.19E-02	8.64E-03	8.84E-03	8.54E-03	8.78E-03	1.38E-02
30% Perc =	9.24E-03	9.08E-03	9.10E-03	9.08E-03	8.81E-03	9.14E-03	1.25E-02	8.97E-03	9.24E-03	8.90E-03	9.11E-03	1.46E-02
35% Perc =	9.53E-03	9.36E-03	9.42E-03	9.41E-03	9.08E-03	9.47E-03	1.30E-02	9.26E-03	9.57E-03	9.18E-03	9.38E-03	1.53E-02
40% Perc =	9.86E-03	9.70E-03	9.68E-03	9.71E-03	9.34E-03	9.74E-03	1.36E-02	9.50E-03	9.85E-03	9.52E-03	9.63E-03	1.61E-02
45% Perc =	1.01E-02	9.90E-03	1.00E-02	1.00E-02	9.65E-03	1.01E-02	1.42E-02	9.84E-03	1.02E-02	9.78E-03	9.94E-03	1.68E-02
50% Perc =	1.04E-02	1.01E-02	1.03E-02	1.02E-02	9.88E-03	1.04E-02	1.48E-02	1.01E-02	1.05E-02	1.00E-02	1.02E-02	1.77E-02
55% Perc =	1.06E-02	1.04E-02	1.05E-02	1.06E-02	1.01E-02	1.07E-02	1.55E-02	1.03E-02	1.08E-02	1.03E-02	1.05E-02	1.87E-02
60% Perc =	1.10E-02	1.07E-02	1.08E-02	1.08E-02	1.04E-02	1.10E-02	1.60E-02	1.05E-02	1.11E-02	1.06E-02	1.07E-02	1.97E-02
65% Perc =	1.13E-02	1.10E-02	1.11E-02	1.12E-02	1.07E-02	1.13E-02	1.67E-02	1.09E-02	1.14E-02	1.09E-02	1.11E-02	2.10E-02
70% Perc =	1.15E-02	1.13E-02	1.14E-02	1.15E-02	1.10E-02	1.16E-02	1.77E-02	1.12E-02	1.17E-02	1.11E-02	1.14E-02	2.23E-02
75% Perc =	1.19E-02	1.17E-02	1.17E-02	1.18E-02	1.14E-02	1.20E-02	1.85E-02	1.16E-02	1.21E-02	1.15E-02	1.17E-02	2.37E-02
80% Perc =	1.23E-02	1.21E-02	1.21E-02	1.23E-02	1.18E-02	1.23E-02	1.94E-02	1.21E-02	1.26E-02	1.18E-02	1.21E-02	2.52E-02
85% Perc =	1.27E-02	1.26E-02	1.27E-02	1.27E-02	1.21E-02	1.28E-02	2.08E-02	1.26E-02	1.30E-02	1.22E-02	1.26E-02	2.78E-02
90% Perc =	1.31E-02	1.30E-02	1.32E-02	1.32E-02	1.27E-02	1.34E-02	2.30E-02	1.32E-02	1.36E-02	1.28E-02	1.31E-02	3.12E-02
95% Perc =	1.36E-02	1.37E-02	1.38E-02	1.40E-02	1.33E-02	1.38E-02	2.61E-02	1.37E-02	1.44E-02	1.32E-02	1.39E-02	3.53E-02

APPENDIX G – STOCHASTIC MODEL SIMULATION SUMMARY STATISTICS UNDER SCENARIO 5 CONDITIONS

Simulation Results for ONSITE-1-1 1

Iterations	1,400
Simulations	1
# Input Variables	136
# Output Variables	13
Sampling Type	Latin hypercube
Runtime	00:01:57

Summary Statistics

	TOP CARNIVORE	WATERFOWL	CARNIVOROUS MAMMALS	HERBIVOROUS MAMMALS	TERRESTRIAL CARNIVOROUS INVERTEBRATES	TERRESTRIAL HERBIVOROUS INVERTEBRATES	TERRESTRIAL PLANTS	CARNIVOROUS FISH	HERBIVOROUS FISH	AQUATIC CARNIVOROUS INVERTEBRATES	AQUATIC HERBIVOROUS INVERTEBRATES	AQUATIC PLANTS
Minimum =	4.96E-03	4.99E-03	5.00E-03	5.06E-03	5.11E-03	5.11E-03	6.42E-03	5.06E-03	5.06E-03	5.24E-03	5.11E-03	5.28E-03
Maximum =	1.48E-02	1.47E-02	1.44E-02	1.46E-02	1.46E-02	1.46E-02	1.54E-02	1.47E-02	1.46E-02	1.48E-02	1.47E-02	1.67E-02
Mean =	1.00E-02	9.91E-03	9.94E-03	9.85E-03	9.80E-03	9.89E-03	1.03E-02	9.82E-03	9.91E-03	1.01E-02	9.80E-03	1.05E-02
Std Deviation =	2.06E-03	2.04E-03	2.02E-03	2.03E-03	2.03E-03	2.03E-03	2.09E-03	2.05E-03	1.99E-03	2.06E-03	2.07E-03	2.20E-03
Variance =	4.25E-06	4.15E-06	4.08E-06	4.10E-06	4.14E-06	4.12E-06	4.36E-06	4.19E-06	3.97E-06	4.24E-06	4.28E-06	4.83E-06
Skewness =	-6.72E-02	-6.91E-02	-9.70E-02	1.76E-02	-5.17E-02	-3.30E-02	4.76E-02	2.88E-02	7.16E-02	-8.22E-02	2.80E-02	6.01E-02
Kurtosis =	2.37E+00	2.41E+00	2.36E+00	2.33E+00	2.43E+00	2.37E+00	2.43E+00	2.40E+00	2.40E+00	2.38E+00	2.35E+00	2.44E+00
Errors Calculated =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mode =	9.86E-03	8.81E-03	9.85E-03	8.89E-03	9.03E-03	1.04E-02	1.12E-02	9.82E-03	9.28E-03	1.04E-02	9.04E-03	1.11E-02
5% Perc =	6.43E-03	6.42E-03	6.52E-03	6.47E-03	6.26E-03	6.48E-03	6.84E-03	6.36E-03	6.70E-03	6.01E-03	6.39E-03	6.91E-03
10% Perc =	7.16E-03	7.08E-03	7.08E-03	7.13E-03	7.04E-03	7.01E-03	7.45E-03	7.07E-03	7.24E-03	7.30E-03	6.95E-03	7.62E-03
15% Perc =	7.73E-03	7.55E-03	7.59E-03	7.57E-03	7.62E-03	7.62E-03	8.01E-03	7.50E-03	7.73E-03	7.78E-03	7.43E-03	8.15E-03
20% Perc =	8.13E-03	8.08E-03	8.13E-03	7.95E-03	7.98E-03	8.00E-03	8.45E-03	7.98E-03	8.08E-03	8.25E-03	7.89E-03	8.61E-03
25% Perc =	8.54E-03	8.45E-03	8.56E-03	8.29E-03	8.30E-03	8.38E-03	8.82E-03	8.36E-03	8.50E-03	8.61E-03	8.37E-03	9.03E-03
30% Perc =	8.91E-03	8.82E-03	8.88E-03	8.69E-03	8.70E-03	8.80E-03	9.18E-03	8.71E-03	8.79E-03	8.98E-03	8.69E-03	9.42E-03
35% Perc =	9.24E-03	9.10E-03	9.20E-03	9.03E-03	9.02E-03	9.10E-03	9.44E-03	8.97E-03	9.08E-03	9.30E-03	8.95E-03	9.65E-03
40% Perc =	9.53E-03	9.39E-03	9.49E-03	9.26E-03	9.28E-03	9.38E-03	9.72E-03	9.32E-03	9.31E-03	9.58E-03	9.18E-03	1.00E-02
45% Perc =	9.80E-03	9.70E-03	9.74E-03	9.57E-03	9.57E-03	9.67E-03	1.00E-02	9.58E-03	9.63E-03	9.87E-03	9.48E-03	1.01E-02
50% Perc =	1.00E-02	1.00E-02	9.96E-03	9.88E-03	9.83E-03	9.94E-03	1.03E-02	9.80E-03	9.89E-03	1.02E-02	9.83E-03	1.05E-02
55% Perc =	1.03E-02	1.02E-02	1.02E-02	1.02E-02	1.01E-02	1.02E-02	1.06E-02	1.01E-02	1.01E-02	1.04E-02	1.01E-02	1.08E-02
60% Perc =	1.05E-02	1.04E-02	1.06E-02	1.04E-02	1.04E-02	1.04E-02	1.09E-02	1.03E-02	1.03E-02	1.07E-02	1.03E-02	1.11E-02
65% Perc =	1.08E-02	1.07E-02	1.08E-02	1.07E-02	1.07E-02	1.07E-02	1.12E-02	1.06E-02	1.06E-02	1.11E-02	1.08E-02	1.14E-02
70% Perc =	1.12E-02	1.11E-02	1.11E-02	1.10E-02	1.10E-02	1.10E-02	1.14E-02	1.09E-02	1.10E-02	1.13E-02	1.09E-02	1.17E-02
75% Perc =	1.15E-02	1.14E-02	1.15E-02	1.13E-02	1.12E-02	1.13E-02	1.18E-02	1.13E-02	1.13E-02	1.16E-02	1.13E-02	1.22E-02
80% Perc =	1.19E-02	1.17E-02	1.18E-02	1.16E-02	1.17E-02	1.17E-02	1.22E-02	1.16E-02	1.17E-02	1.20E-02	1.17E-02	1.26E-02
85% Perc =	1.23E-02	1.22E-02	1.22E-02	1.21E-02	1.21E-02	1.21E-02	1.26E-02	1.21E-02	1.22E-02	1.24E-02	1.21E-02	1.30E-02
90% Perc =	1.28E-02	1.26E-02	1.26E-02	1.26E-02	1.25E-02	1.26E-02	1.31E-02	1.26E-02	1.27E-02	1.28E-02	1.27E-02	1.38E-02
95% Perc =	1.34E-02	1.33E-02	1.33E-02	1.33E-02	1.30E-02	1.32E-02	1.36E-02	1.34E-02	1.33E-02	1.36E-02	1.32E-02	1.44E-02

APPENDIX H – STOCHASTIC MODEL SIMULATION SUMMARY STATISTICS UNDER SCENARIO 6 CONDITIONS

Simulation Results for ONSITE-3H.1

Iterations	750
Simulations	1
# Input Variables	138
# Output Variables	12
Sampling Type	Latin hypercube
Runtime	00:00:02

Summary Statistics

	TOP CARNIVORE	WATERFOWL	CARNIVOROUS MAMMALS	HERBIVOROUS MAMMALS	TERRESTRIAL CARNIVOROUS INVERTEBRATES	TERRESTRIAL HERBIVOROUS INVERTEBRATES	TERRESTRIAL PLANTS	CARNIVOROUS FISH	HERBIVOROUS FISH	AQUATIC CARNIVOROUS INVERTEBRATES	AQUATIC HERBIVOROUS INVERTEBRATES	AQUATIC PLANTS
Minimum =	5.06E-03	5.21E-03	5.06E-03	4.98E-03	5.11E-03	5.14E-03	5.21E-03	4.98E-03	5.06E-03	5.08E-03	5.19E-03	5.47E-03
Maximum =	1.45E-02	1.48E-02	1.44E-02	1.45E-02	1.48E-02	1.46E-02	1.48E-02	1.45E-02	1.47E-02	1.46E-02	1.48E-02	1.65E-02
Mean =	9.67E-03	9.86E-03	9.74E-03	9.82E-03	9.96E-03	9.84E-03	1.01E-02	9.80E-03	9.74E-03	1.00E-02	9.92E-03	1.03E-02
Std Deviation =	2.05E-03	1.93E-03	1.94E-03	1.98E-03	2.02E-03	1.98E-03	1.98E-03	2.01E-03	2.01E-03	1.99E-03	2.00E-03	2.11E-03
Variance =	4.21E-06	3.74E-06	3.76E-06	3.94E-06	4.09E-06	3.94E-06	3.92E-06	4.04E-06	4.04E-06	3.95E-06	4.01E-06	4.47E-06
Skewness =	-6.08E-03	-6.08E-02	1.47E-02	2.17E-02	-5.36E-02	4.19E-02	-4.20E-02	-8.06E-02	1.48E-01	-1.23E-02	6.88E-02	-4.91E-03
Kurtosis =	2.25E+00	2.46E+00	2.30E+00	2.47E+00	2.38E+00	2.40E+00	2.45E+00	2.36E+00	2.43E+00	2.46E+00	2.28E+00	2.37E+00
Errors Calculated =	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mode =	1.04E-02	9.88E-03	6.79E-03	1.02E-02	7.93E-03	8.42E-03	1.09E-02	1.22E-02	1.11E-02	8.71E-03	9.52E-03	9.94E-03
5% Perc =	6.58E-03	6.67E-03	6.49E-03	6.48E-03	6.58E-03	6.49E-03	6.67E-03	6.37E-03	6.52E-03	6.63E-03	6.73E-03	6.83E-03
10% Perc =	7.04E-03	7.18E-03	7.12E-03	7.22E-03	7.23E-03	7.14E-03	7.45E-03	7.01E-03	6.94E-03	7.36E-03	7.29E-03	7.33E-03
15% Perc =	7.66E-03	7.68E-03	7.66E-03	7.67E-03	7.71E-03	7.66E-03	7.94E-03	7.58E-03	7.58E-03	7.64E-03	7.68E-03	7.90E-03
20% Perc =	7.97E-03	8.09E-03	8.00E-03	8.06E-03	8.07E-03	8.03E-03	8.30E-03	8.02E-03	7.91E-03	8.28E-03	8.03E-03	8.38E-03
25% Perc =	8.38E-03	8.63E-03	8.28E-03	8.38E-03	8.58E-03	8.42E-03	8.82E-03	8.38E-03	8.32E-03	8.64E-03	8.43E-03	8.73E-03
30% Perc =	8.65E-03	8.98E-03	8.61E-03	8.72E-03	8.83E-03	8.73E-03	9.09E-03	8.68E-03	8.63E-03	8.93E-03	8.72E-03	9.15E-03
35% Perc =	8.87E-03	9.28E-03	8.88E-03	9.00E-03	9.11E-03	9.07E-03	9.41E-03	8.92E-03	8.94E-03	9.21E-03	8.98E-03	9.48E-03
40% Perc =	9.21E-03	9.48E-03	9.13E-03	9.27E-03	9.49E-03	9.32E-03	9.69E-03	9.28E-03	9.13E-03	9.50E-03	9.33E-03	9.79E-03
45% Perc =	9.52E-03	9.69E-03	9.45E-03	9.53E-03	9.77E-03	9.54E-03	9.98E-03	9.58E-03	9.39E-03	9.73E-03	9.61E-03	9.98E-03
50% Perc =	9.91E-03	9.93E-03	9.72E-03	9.77E-03	9.98E-03	9.84E-03	1.02E-02	9.80E-03	9.68E-03	9.98E-03	9.82E-03	1.03E-02
55% Perc =	1.02E-02	1.03E-02	1.00E-02	1.01E-02	1.03E-02	1.00E-02	1.04E-02	1.01E-02	9.94E-03	1.03E-02	1.01E-02	1.06E-02
60% Perc =	1.05E-02	1.05E-02	1.02E-02	1.03E-02	1.05E-02	1.03E-02	1.07E-02	1.04E-02	1.02E-02	1.05E-02	1.04E-02	1.08E-02
65% Perc =	1.08E-02	1.07E-02	1.05E-02	1.06E-02	1.08E-02	1.06E-02	1.08E-02	1.07E-02	1.04E-02	1.08E-02	1.07E-02	1.11E-02
70% Perc =	1.11E-02	1.09E-02	1.08E-02	1.09E-02	1.11E-02	1.09E-02	1.12E-02	1.10E-02	1.07E-02	1.11E-02	1.11E-02	1.15E-02
75% Perc =	1.14E-02	1.13E-02	1.12E-02	1.12E-02	1.15E-02	1.12E-02	1.15E-02	1.13E-02	1.11E-02	1.14E-02	1.14E-02	1.18E-02
80% Perc =	1.16E-02	1.15E-02	1.15E-02	1.16E-02	1.19E-02	1.16E-02	1.20E-02	1.17E-02	1.15E-02	1.18E-02	1.18E-02	1.22E-02
85% Perc =	1.21E-02	1.19E-02	1.20E-02	1.21E-02	1.23E-02	1.20E-02	1.23E-02	1.21E-02	1.20E-02	1.22E-02	1.23E-02	1.28E-02
90% Perc =	1.26E-02	1.23E-02	1.24E-02	1.27E-02	1.28E-02	1.28E-02	1.27E-02	1.25E-02	1.26E-02	1.27E-02	1.27E-02	1.32E-02
95% Perc =	1.33E-02	1.32E-02	1.29E-02	1.31E-02	1.32E-02	1.33E-02	1.34E-02	1.30E-02	1.33E-02	1.33E-02	1.33E-02	1.35E-02

2

VITA

Michael L. Thayer

Candidate for the Degree of

Master of Science

Thesis: COMPARTMENT-BASED WETLAND ECOSYSTEM CONTAMINANT TRANSFER MODEL FOR ASSESSING ECOSYSTEM RISK

Major Field: Environmental Science

Biographical:

Personal Data: Born in Tulsa, Oklahoma on 13 April 1970, the son of David and Ann Thayer. Husband of Lisa Thayer and father of Sarah and David Thayer.

Education: Graduated from Nathan Hale High School, Tulsa, Oklahoma in May 1988; received Associate of Science degree in Biology from Tulsa Community College in May 1991; received Bachelor of Science degree in Wildlife Biology from Northeastern State University, Tahlequah, Oklahoma in May 1994. Completed the requirements for the Master of Science degree with a major in Environmental Science at Oklahoma State University, Stillwater, Oklahoma in May 2000.

Experience: Laboratory Technician for ICI Explosives, Inc. in Joplin, Missouri, January 1992 to August 1992; worked two summers (1993 and 1994) with the U.S. Fish and Wildlife Service restoring wetland ecosystem habitats throughout the State of Oklahoma; employed as Physiology Laboratory Assistant at Northeastern State University during Fall (1993) and Spring (1994) semesters; employed by Fibercast Company, Sand Springs, Oklahoma as Environmental Coordinator, 1996 to present.