

EVALUATION OF BIOACCUMULATION MODELS FOR TERRESTRIAL ECOLOGICAL RISK ASSESSMENT

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ABSTRACT

Three approaches to predicting dietary intakes for high trophic level species such as raptors are presented. Data collected to support the site-wide ecological risk assessment at Tooele Army Depot, Tooele, Utah, were used to determine the inherent strengths and weaknesses of the different approaches. One approach is to use literature data to develop bioaccumulation factors (BAFs); these BAFs were then used in conjunction with measured soil concentrations to estimate tissue concentrations in lower trophic levels at locations without biota data. Another approach is to measure prey tissue concentrations as well as soil concentrations at various locations, and estimate site-specific BAFs from the measured data. The site-specific BAFs can be used to predict prey tissue concentrations from soil data at locations lacking biological data. Dietary intakes for higher trophic level species can then be predicted at locations without biota data from predicted tissue concentrations and measured soil concentrations. A third approach uses the same measured soil and biota data, but applies a dynamic food web model that can be used to simulate changes in tissue concentration over time. The output of the model is a tissue concentration for each modeled prey or forage species; this then provides the exposure point concentration for estimating the dietary ingestion pathway.

INTRODUCTION

Tooele Army Depot (TEAD) is located 35 miles southwest of Salt Lake City, Utah. The area of TEAD is approximately 25,000 acres (Figure 1). An ecological risk assessment was conducted at TEAD from 1994 to 1997 as part of ongoing efforts to identify and characterize potential adverse effects of contamination on the environment as required by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP, 40CFR Part 300). As part of the ecological risk assessment, soil, vegetation, terrestrial invertebrates, and small mammals were collected from several solid waste management units (SWMUs) within TEAD, and from a nearby reference study area (RSA). The RSA is located approximately 5 miles due south of the TEAD facility, and encompasses approximately 6400 acres of mostly Bureau of Land Management (BLM) lands.

TEAD is classified as a cold semi-desert, characterized by sagebrush and saltbush plant species. Army activities at TEAD included manufacture and disposal of munitions, weapons testing, as well as equipment repair and storage. Metals and some organics are elevated at TEAD as a result of Army-related activities. In order to evaluate potential ecological risk due to dietary exposure, the concentrations in prey or forage items must be estimated or measured. One procedure is to use literature data for bioaccumulation factors (BAFs), and estimate concentrations in lower trophic levels from measured soil concentrations. Another approach is to measure chemical contaminants in soil and tissue. Dietary intakes for higher trophic level species can then be predicted at the sampling locations from the measured data. In addition, the data can be used to calculate BAFs from which to predict tissue concentrations, and the resulting dietary intakes from soil data at locations lacking biological data. A third approach uses the same measured soil and biota data, but applies a dynamic food web model that can be used to simulate changes in tissue concentration over time. The output of the model is a tissue concentration for each modeled prey or forage species; this then provides the exposure point concentration for estimating the dietary ingestion pathway intakes. Following calibration of the model with site-specific data, the model can be applied at other onsite locations to predict tissue concentrations. Each approach has inherent strengths and limitations, which are discussed in this paper.

METHODS

The methods used to investigate each approach for estimating the dietary ingestion pathway are described below. For the purposes of this paper, lead and zinc were selected from numerous modeled contaminants (e.g., inorganics, dioxins, furans, pesticides, explosives, and polynuclear aromatic hydrocarbons) to demonstrate the different modeling processes [1]. The arithmetic mean concentrations ($\pm$ standard deviation) for lead and zinc concentrations observed in soil, plants, terrestrial invertebrates, and black-tailed jackrabbits at each location are presented in Table I. The species sampled for chemical analysis were gumweed (*Grindelia squarrosa*), rabbitbrush (*Chrysothamnus spp.*), sweetclover (*Melilotus spp.*), grasshoppers (Orthoptera), beetles (Coleoptera), and black-tailed jackrabbit (*Lepus californicus*).

Literature-Based Bioaccumulation Approach

This approach requires the least amount of site-specific data. However, a thorough literature review is necessary to obtain information that can be used to derive BAFs. Table II presents a summary of the results of a literature review for bioaccumulation factors for lead and zinc. For some analytes, these data may be lacking. A BAF for each receptor is obtained from the literature review; the BAF is multiplied by the site-specific soil concentration to predict tissue concentrations (Table III). Although Table III uses the arithmetic mean BAF for demonstration purposes, the median or geometric mean could be more appropriate measures of central tendency, depending on the underlying data distribution. Often in risk assessments, the maximum value and not the measure of central tendency is applied in order to obtain a conservative estimate. The end result of this type of approach does not account for spatial variation, effects of site characteristics on the bioaccumulation process, or variations in physiology between the test species and the ecological receptors at the site. This can lead to the over- or under-estimation of predicted tissue concentrations and the resulting dietary intakes.

Site-Specific Bioaccumulation Factor Approach

A simplified food web was developed for the terrestrial dietary exposure modeling effort (Figure 2). Of the species illustrated in the simplified food web, only vegetation, terrestrial invertebrates, and black-tailed jackrabbits were collected and analyzed. Samples were collected from 10 different locations on TEAD, and from the RSA. Chemical analysis of soils was performed at co-located sampling locations within five to 10 meters of the vegetation samples. Invertebrate samples were collected at five of the co-located sampling locations on TEAD, and at the RSA; these sites overlapped the 10 locations where plant samples were collected. Due to the scarcity of invertebrate material for collection, it was necessary to composite species from each of the SWMU groupings (i.e., SWMUs 1b/1c, 10/11, 12/15, 21/37, and 42/45). Black-tailed jackrabbits were collected from one TEAD location (SWMUs 42/45), and at the RSA (Table I).

Site-specific BAFs were calculated by dividing the mean tissue concentrations in plants, invertebrates, and jackrabbits at the RSA by the mean soil concentrations at the RSA. This resulted in BAFs that reflected conditions and biological receptors in the immediate vicinity of TEAD. The site-specific BAFs were then applied at onsite locations lacking biological data in order to predict tissue concentrations in lower trophic levels (Table III). This approach has the advantage of utilizing both site-specific data and taxa to predict dietary intakes for higher trophic level species, but minimizes the number of locations for which biotic data are required. However, this approach does not help to explain the mechanisms that underlie bioaccumulation processes. In addition, sampling may fail to represent all site-specific characteristics that may affect bioaccumulation. Inherent in the application of the modeling approaches utilizing BAFs is the assumption that the tissue concentrations are at steady state with the environmental concentrations, which may or may not be true.

Dynamic Food Web Model

Because of the large number of potentially contaminated SWMUs on TEAD, and the high cost of biological sampling, a dynamic food web model was developed to predict concentrations in plants, terrestrial invertebrates, and black-tailed jackrabbits. Jackrabbit samples were not collected at all locations; therefore, observed jackrabbit data are missing from some locations (Table I).

The model is essentially a series of linked differential equations. The model was calibrated with data from the RSA by adjusting the species specific uptake and loss parameters until the modeled RSA tissue concentrations for plants, invertebrates, and jackrabbits were in close agreement with the measured data. Data from the 10 TEAD SWMUs were used to validate the model by substituting the soil concentration into the model, and holding the parameters at the calibrated values. Model runs were performed for each of the 10 SWMUs, and the results were averaged into the five SWMU groupings for presentation (Table III).

Plants were assumed to obtain their entire chemical content from soil; airborne fallout onto leaves was not estimated. Invertebrates were also assumed to obtain all chemical exposure by direct contact with soil.

These assumptions lead to a generalization for plants and invertebrates that the tissue concentration over time is related to uptake multiplied by the soil concentration. The tissue concentration in the lower trophic levels is also dependent on elimination relative to the concentration in the organism:

$$Eq. 1 \quad \frac{dC_{plant}}{dt} = k1_{plant} * C_{soil} - k2_{plant} * C_{plant}$$

$$Eq. 2 \quad \frac{dC_{bug}}{dt} = k1_{bug} * C_{soil} - k2_{bug} * C_{bug}$$

where: C_{plant} = tissue concentration as a function of time in plants(mg/kg)
 C_{bug} = tissue concentration as a function of time in invertebrates (mg/kg)
 $k1_i$ = uptake rate (day⁻¹) for receptor i
 $k2_i$ = loss rate (day⁻¹) for receptor i
 C_{soil} = average soil concentration (mg/kg); location-specific

While the assumption that tissue concentrations can be related to soil is probably reasonable for plants, it represents a simplification for invertebrates in that some of their tissue concentrations relate to dietary ingestion of plants, detritus, or other food items. A more elaborate model would separate invertebrates into multiple feeding categories consisting of herbivores, omnivores, and carnivores. This level of detail was not explored.

Jackrabbits were assumed to obtain a fraction of their body burden from soil, and a fraction from the plants as defined by the parameters SIR and DIR as follows:

$$Eq. 3 \quad \frac{dC_{jr}}{dt} = (DIR * C_{plant} * AF_{jr}) + (SIR * C_{soil} * AF_{jr}) - (C_{jr} * Kel)$$

where: DIR = dietary ingestion rate for jackrabbit (kg diet/kg bw/day)
 C_{jr} = tissue concentration in jackrabbit (mg/kg)
 AF_{jr} = assimilation fraction for jackrabbit (unitless)
SIR = soil ingestion rate for jackrabbit (kg soil/kg bw/day)
Kel = loss rate for jackrabbit (day⁻¹)
 C_{plant} = tissue concentration in vegetation (mg/kg)

The dietary ingestion rate for jackrabbits (DIR) was estimated from the following allometric equation [16]:

$$Eq. 4 \quad DIR (kg/kg bw/d) = \frac{0.577 * Wt(g)^{0.727}}{Wt(g)}$$

Body weight data were collected during sampling activities at TEAD. The average body weight for jackrabbits from TEAD was 1220 g. The DIR used in the dynamic food web model was 0.098 kg/kg bw/d. The fraction of soil in the

diet used in the model was assumed to be 0.02 based on data for other herbivores [17]; the SIR was calculated as the soil fraction in diet multiplied by the DIR. The soil ingestion rate for jackrabbits was fixed for all of the model runs.

The model was coded into Time0 (Quaternary Software, Fort Collins, Colorado) which simplifies model development by reducing the amount of computer code necessary. The average RSA soil concentrations for lead and zinc were entered into the parameter file as C_{soil} . The uptake and loss rates for plants were initially set at 0.05 day^{-1} , and then adjusted up or down until the plant tissue concentrations approximated those observed at the RSA within a model run of 300 days. The uptake and loss rates for invertebrates and jackrabbits were initially set at 0.01 day^{-1} , and adjusted until the tissue concentrations approximated those at the RSA. Table 4 presents the parameters used in the calibrated model for lead and zinc. After the model was calibrated with the RSA soil and biota data, the soil concentrations for the TEAD study areas were substituted for that at the RSA, and the output examined to determine how closely plant, invertebrate, and jackrabbit concentrations were predicted.

RESULTS AND DISCUSSION

The purpose of bioaccumulation models as applied to ecological risk assessment typically is to predict tissue concentrations of various analytes in lower trophic level species. The model predictions can then be used to estimate dietary intakes by higher trophic level species such as raptors. While it is obvious to assume that collecting site-specific data would decrease uncertainty in the risk assessment results, often this step is neglected and literature-based information is relied upon. While this is sufficient for screening purposes, it may introduce unreasonable amounts of error into estimates of the dietary ingestion pathway.

Each of the modeling approaches presented herein ultimately provided an estimate of tissue concentrations in prey species as some proportion of the ambient soil concentrations. However, the different approaches differ in how closely they approximate the measured data (Figures 3 and 4). Because the RSA data were used to develop a site-specific BAF and to calibrate the dynamic model, there are no predicted tissue concentrations by these two models at the RSA (Figures 3 and 4).

The predicted tissue concentrations of lead in plants and invertebrates based on the literature BAFs generally exhibited the poorest fit to the measured data (Figure 3). The tissue concentrations based on the site-specific BAFs and the dynamic model more often follow the measured data (Figure 3). The two models that used site-specific data performed very similarly to each other. At each of the locations investigated at TEAD, the mean literature-based BAF overestimated mean measured plant concentrations by factors ranging from 2.0 to 172.9. Mean measured lead concentrations in invertebrates were overestimated by literature-based BAFs by factors ranging from 69.9 to 2163.2. Tissue concentrations in jackrabbits were underestimated by the literature-based BAFs, although with only two sites providing jackrabbit tissue, the results are not conclusive. Predicted lead concentrations in plants were within factors of 1.4 to 37.6 for plants and within factors of 1.3 to 23.0 for invertebrates based on the mean site-specific BAFs or the dynamic model. Obviously, the predicted dietary intakes of lead for higher trophic level receptors are much less uncertain when based on measured data or predicted with BAFs derived from site-specific data. The models that used the site data did not consistently over-predict tissue lead concentrations, as did the literature-based model.

It is important to note that as soil lead concentrations increased, so did the error with which all models predicted lead tissue concentrations. The site with the highest lead concentration (SWMUs 10/11) exhibited the greatest amount of error between the predicted and mean measured concentrations. In this demonstration, average values were used to represent the BAFs and the measured site data. However, maximum values are often used to conservatively represent the soil exposure point concentrations in risk assessments; maximum BAFs may also be used to conservatively estimate bioaccumulation. Use of maximum literature-based BAF values, especially in conjunction with maximum soil concentrations as the exposure point concentration, would obviously increase the predicted errors even more, and therefore the uncertainty in the dietary ingestion pathway.

The predicted tissue concentrations of zinc (Figure 4) in plants and invertebrates based on the literature BAFs generally exhibited a better fit to the measured data than did lead. At each of the locations investigated at TEAD, the mean literature-based zinc BAF for plants overestimated mean measured plant concentrations of zinc by factors ranging from 2.6 to 26.3. Mean measured lead concentrations in invertebrates were within concentrations predicted

by literature-based BAFs by factors ranging from only 1.2 to 8.0; invertebrate tissue concentrations of zinc were both over- and under-estimated. However, the literature-based BAF predicts zinc concentrations in invertebrates at TEAD within an order of magnitude. These results indicate that prediction of zinc tissue concentrations for invertebrates does not introduce much uncertainty into estimates of the TEAD dietary ingestion pathways. Whether these results would be similar at different sites is not known. The plant tissue concentrations based on the average site-specific BAFs follow the measured data even more closely (Figure 4), where predicted tissue concentrations differed from the mean zinc concentrations measured in plants by factors ranging from only 1.1 to 5.1; predicted tissue concentrations were higher or lower than measured data. The dynamic model consistently over-predicted zinc concentrations in plant tissue at factors ranging from 1.1 to 11.0. As with lead, collection of site-specific data improved the estimates of plant tissue concentrations, and thereby estimates of the dietary ingestion pathway.

The site-specific BAFs for zinc did not perform as well for the invertebrates as did the literature-based BAFs, particularly at sites where the soil concentrations were more than twice that at the reference area, from which the site-specific models were calibrated. The site-specific BAFs consistently over-predicted tissue concentrations of zinc at all locations (Table III). This may be because zinc is a required nutrient for invertebrates, and at the RSA, active uptake was occurring to support nutritional requirements. However, at the sites with higher soil concentrations (Table I), physiological regulatory mechanisms slowed the uptake of zinc, making a BAF measured at low soil concentrations inappropriate for use at a location where soil concentrations were high. This type of bimodal uptake pattern could be expected to occur for any of the analytes that are also nutrients. The dynamic model performed better than the site-specific BAF, as predicted tissue concentrations of zinc were within 1.9 to 13.3 times that of the mean measured zinc concentrations.

Mean zinc tissue concentrations in jackrabbits were within 1.7 to 2.4 times the tissue concentrations predicted from the literature-based BAFs, although with only two sites providing jackrabbit tissue, this is not conclusive. The site-specific BAF overestimated zinc concentrations in jackrabbits, again possibly because zinc is a nutrient that is modulated by the body to meet nutritional requirements. The dynamic model performed similarly to the literature-based BAFs. It is important to note that as with lead, the error with which all models predicted zinc tissue concentrations in plants and invertebrates was highest where soil zinc concentrations were highest (SWMUs 10/11).

Other statistics besides the mean or the maximum that could be used in a risk assessment are the geometric mean or the median values for soil concentrations and BAFs. A geometric mean is appropriate as the measure of central tendency when the data are lognormal. The median is often a more robust measure of central tendency than the mean. In the example presented herein, the literature-based plant BAFs followed a lognormal distribution for lead. The literature-based invertebrate and mammalian BAFs for lead were neither normal nor lognormal. These results indicate that while the geometric mean would be a more appropriate measure of central tendency for plant lead BAFs, the median would be more appropriate for invertebrates or mammals (Table II). The literature-based plant BAFs may or may not have followed a normal distribution for zinc, as only two BAFs were found in the literature reviewed for the TEAD ecological risk assessment. The literature-based invertebrate and mammalian BAFs for zinc were normally distributed. Therefore, use of the arithmetic mean is an appropriate measure of the literature-based BAFs for zinc (Table II). This exercise indicates that caution should be used when selecting a BAF from the literature to use in a dietary ingestion pathway in an ecological risk assessment; the underlying statistical distribution should be verified prior to arbitrarily using a geometric or arithmetic mean as a measure of central tendency.

One advantage to utilizing the dynamic model is that intermittent exposure can be modeled if necessary by adjusting the model code prior to running a simulation, as in the case of a seasonal migrant. This could be done by changing the duration of exposure (dt) to reflect part of the life cycle where C_{soil} contains contaminant, and the other part of the life cycle where C_{soil} was a lower value or even zero. As part of the dynamic model, uptake and loss rates for the modeled taxa are predicted as part of model calibration. Loss rates predicted for invertebrates at TEAD compared fairly well to those reported by other authors whose results indicated that excretion rates of zinc in grasshoppers at nine days after an exposure were approximately only 10% of the original body burden [18].

Bioaccumulation models are required for locations or sites for which biota data are not available, but estimates of the dietary ingestion pathway are deemed necessary by the risk managers in order to facilitate remedial activities. Modeling provides a cost effective, technically justifiable way of predicting dietary intakes at numerous sites for which biota data are not available, in order that the dietary ingestion pathway can be quantitatively addressed in the

ecological risk assessment. Literature-based BAFs are sufficient for highly conservative screening level assessments, but site-specific data should be collected in the event that excessive ecological risks are projected for the dietary ingestion pathway. While tissue data are costly to obtain, the potential savings by reducing the area that requires remediation can more than offset the laboratory and field data collection costs. Furthermore, remediation can destroy habitat on a temporary or permanent basis, and unnecessary remediation is therefore to be avoided from an ecological cost perspective.

Our conclusions are that in order to estimate the contribution of the dietary pathway in a risk assessment with any degree of certainty, at least limited tissue data from the site should be collected. Extrapolation from soil to biological tissues with a literature-based value could be done in a screening level assessment, but there is no basis for assuming that the resulting dietary intakes would be within even an order of magnitude of actual values. As the tissue concentrations could be either under or overestimated, there is also no basis for assuming that risk estimates would be conservative. The literature-based BAFs predicted zinc concentrations better in animals than did the site-specific BAF or the dynamic model, possibly because laboratory test conditions producing the BAFs exposed animals to higher levels than environmental exposure of animals at the reference area, from which data were used to calibrate the site-specific models. If zinc exhibits a bimodal accumulation pattern, as the data suggest, the BAFs will decrease with increasing soil concentrations. This means that the most appropriate literature-based BAFs to reflect zinc uptake will be those from studies where daily intakes approximate those at a given site.

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ACKNOWLEDGEMENTS

The data reported in this article were collected as part of work performed for the U.S. Army under Contract #DAAA15-90-D-0007, Task Order 0003.

Table I. Summary of Measured Data by Location.

Matrix	SWMU	LEAD						ZINC					
		n	Detection Frequency (%)	Minimum Value	Maximum Value	Arithmetic Mean	Standard Deviation	n	Detection Frequency (%)	Minimum Value	Maximum Value	Arithmetic Mean	Standard Deviation
Soil	10/11	3	33	3.72	1500	751.9	1058	3	100	20.40	843.0	432.5	580.6
	12/15	4	100	70.9	224.0	100.7	42.17	4	100	52.70	594.0	201.6	210.6
	21/37	4	75	3.72	836.0	226.8	312.4	4	100	37.20	492.0	156.8	166.4
	42/45	15	100	17.2	822.0	322.4	156.3	15	100	8.46	518.0	146.8	121.5
	1B/1C	4	100	11.00	28.60	19.43	7.46	4	100	37.4	99.90	58.90	24.32
	RSA	16	100	3.72	73.30	19.65	15.25	16	100	8.32	127.0	33.64	32.88
Plant	10/11	6	100	0.40	1.70	1.00	0.33	6	100	11.00	24.00	19.60	5.79
	12/15	8	100	0.58	2.80	1.45	0.57	8	100	2.30	146.0	51.40	57.60
	21/37	9	100	0.33	147.0	26.55	38.93	9	100	7.10	154.0	37.25	37.84
	42/45	29	100	0.64	71.40	12.20	12.70	29	100	1.90	39.30	15.69	10.99
	1B/1C	8	100	0.35	1.70	0.70	0.35	8	100	5.90	54.70	26.90	10.08
	RSA	37	100	0.29	2.70	0.96	0.46	37	100	2.00	24.30	11.08	6.46
Invertebrate	10/11	5	100	0.47	0.87	0.65	0.17	5	100	44.20	58.30	52.40	6.91
	12/15	6	67	0.15	0.85	0.41	0.27	6	100	53.00	61.60	58.80	3.21
	21/37	5	100	0.51	14.10	3.46	5.95	5	100	43.00	60.60	54.70	6.82
	42/45	5	100	0.36	3.90	1.54	1.59	5	100	53.50	60.50	57.70	2.69
	1B/1C	3	100	0.34	0.85	0.52	0.28	3	100	35.80	60.80	49.50	12.68
	RSA	13	77	0.14	0.79	0.39	0.18	13	100	39.10	67.90	51.60	7.55
Jackrabbit	10/11	ND	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA
	12/15	ND	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA
	21/37	ND	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA
	42/45	15	100	1.80	405	75.87	113.0	15	100	18.90	24.10	21.90	1.53
	1B/1C	ND	NA	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA
	RSA	15	100	0.26	56.70	13.16	16.53	15	100	19.10	23.30	20.90	1.40

Table II. Literature Based Bioaccumulation Factors (Source:[2]-[15]).

Analyte	Plants				Invertebrates				Jackrabbits			
	Geometric Mean	Median	Mean	SD	Geometric Mean	Median	Mean	SD	Geometric Mean	Median	Mean	SD
Lead	0.13	0.11	0.23	0.39	0.07	0.03	1.87	5.75	0.001	0.001	0.01	0.03
Zinc	0.55	1.19	1.19	1.49	0.66	0.97	0.97	0.70	0.11	0.07	0.26	0.40

Table III. Tissue Concentrations (mg/kg) Predicted by the Different Modeling Approaches

Zinc									
Location	Literature Based BAF Approach			Site Data BAF Approach			Dynamic Food Web Model Approach (@ 300 Days)		
	Plant	Invertebrate	Jackrabbit	Plant	Invertebrate	Jackrabbit	Plant	Invertebrate	Jackrabbit
SWMU 1B/1C	70.09	57.13	15.31	13.55	338.68	0.59	29.45	95.21	4.32
SWMU 10/11	514.68	419.53	112.45	99.48	2486.88	4.33	216.22	699.09	287.49
SWMU 12/15	239.90	195.55	52.42	46.37	1159.20	2.02	82.91	268.09	110.25
SWMU 21/37	186.59	152.10	40.77	36.06	901.60	1.57	78.40	253.51	11.50
SWMU 42/45	174.69	142.40	38.7	33.76	844.10	1.47	73.41	237.35	10.77
RSA	40.03	32.63	8.75	NA	NA	NA	NA	NA	NA
Lead									
Location	Literature Based BAF Approach			Site Data BAF Approach			Dynamic Food Web Model Approach (@ 300 Days)		
	Plant	Invertebrate	Jackrabbit	Plant	Invertebrate	Jackrabbit	Plant	Invertebrate	Jackrabbit
SWMU 1B/1C	4.49	36.24	0.18	0.92	0.38	13.05	0.97	0.39	7.81
SWMU 10/11	173.85	1402.74	6.87	35.71	14.85	505.19	37.59	15.04	3.77
SWMU 12/15	23.28	187.88	0.92	4.78	1.99	67.66	5.04	2.02	40.50
SWMU 21/37	52.46	423.25	2.07	10.77	4.48	152.43	11.35	4.53	91.19
SWMU 42/45	74.55	601.50	2.95	15.31	6.37	216.63	16.10	6.45	129.60
RSA	4.54	36.65	0.18	NA	NA	NA	NA	NA	NA

NA – Not applicable because the RSA data were used to calibrate the site-specific models

Table IV. Parameters Used in the Bioaccumulation Model.

Parameter	Zinc	Lead	Definition	Note	Units
C_{soil}	--	--	Average site specific soil concentrations	Varies	mg/kg
DIR	0.098	0.098	daily dietary ingestion rate for jackrabbits	Fixed	kg/kg bw/day
AF_{j_r}	0.5	0.6	assimilation fraction for jackrabbits	Varies	unitless
SIR	1.96E-3	1.96E-3	daily soil ingestion rate for jackrabbits	Fixed	kg/kg bw/day
Kel	0.03	0.009	loss rate for jackrabbits	Varies	1/day
$k1_{\text{plant}}$	0.025	0.01	uptake rate for plants	Varies	1/day
$k2_{\text{plant}}$	0.05	0.2	loss rate for plants	Varies	1/day
AUF_{j_r}	1	1	area use factor for jackrabbit	Fixed	unitless
INTK	0.3	0.3	daily dietary ingestion rate for raptors	Fixed	kg/kg bw/day
AUF_r	1	1	area use factor for raptors	Fixed	unitless
$k1_{\text{bug}}$	0.07	0.01	uptake rate for invertebrates	Varies	1/day
$k2_{\text{bug}}$	0.0433	0.5	loss rate for invertebrates	Varies	1/day

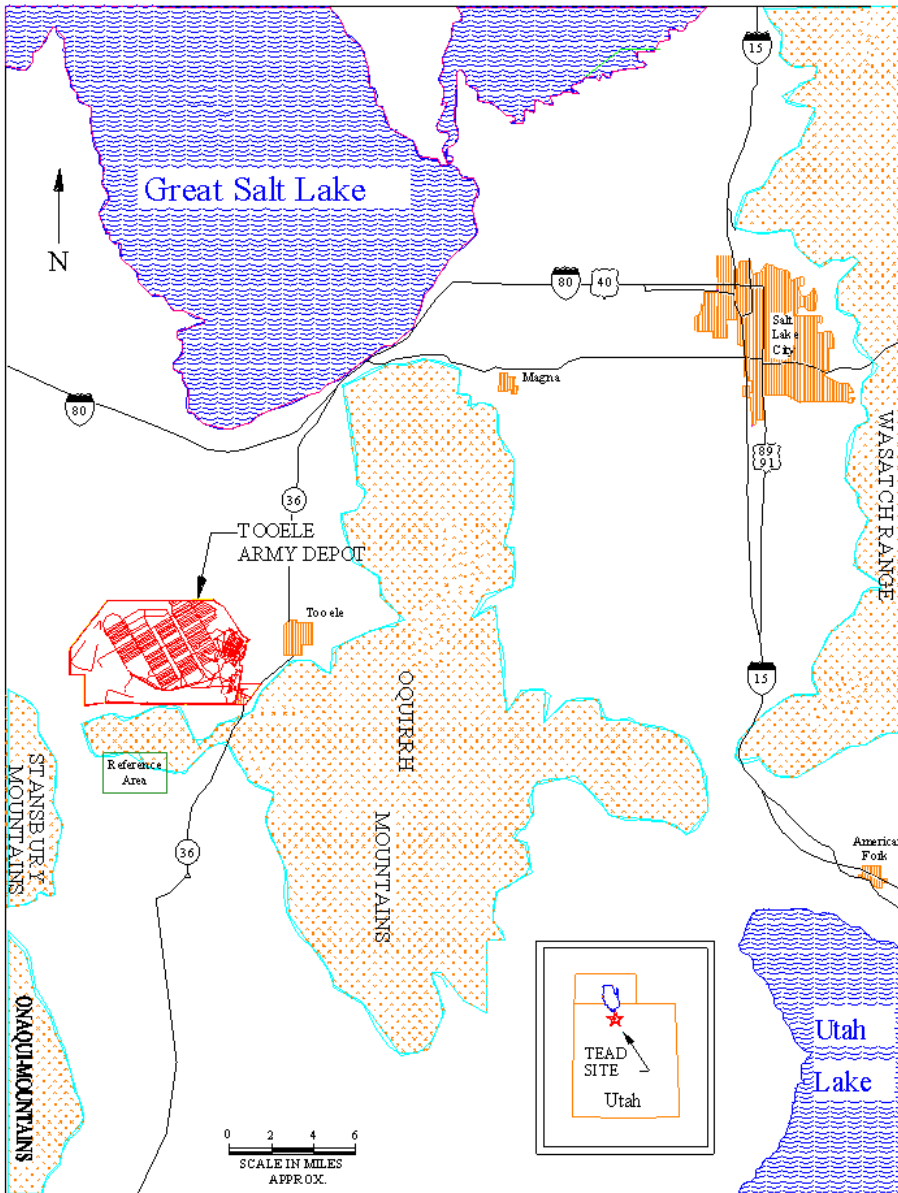
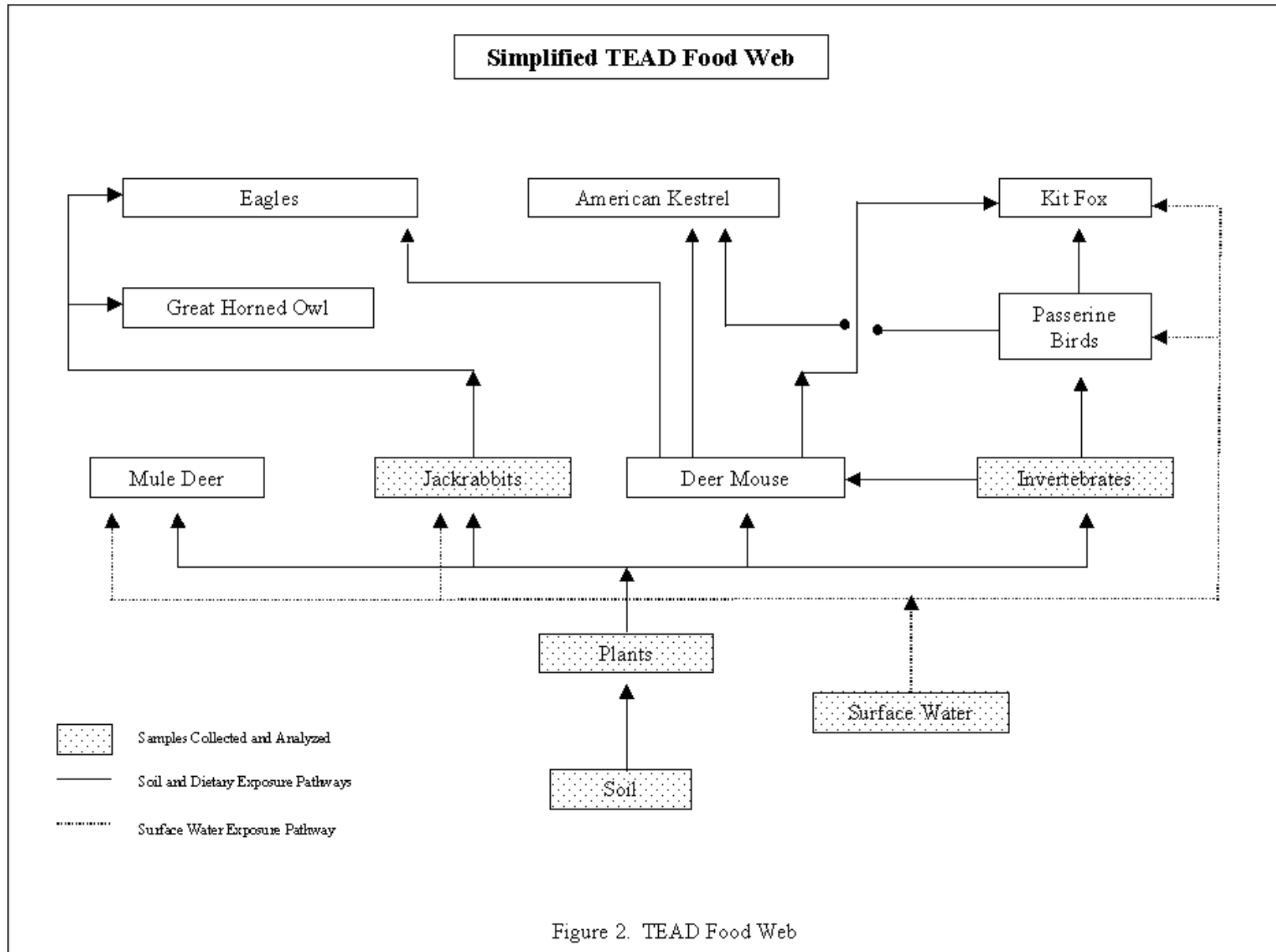


Figure 1. Location Map for TEAD and the Reference Study Area



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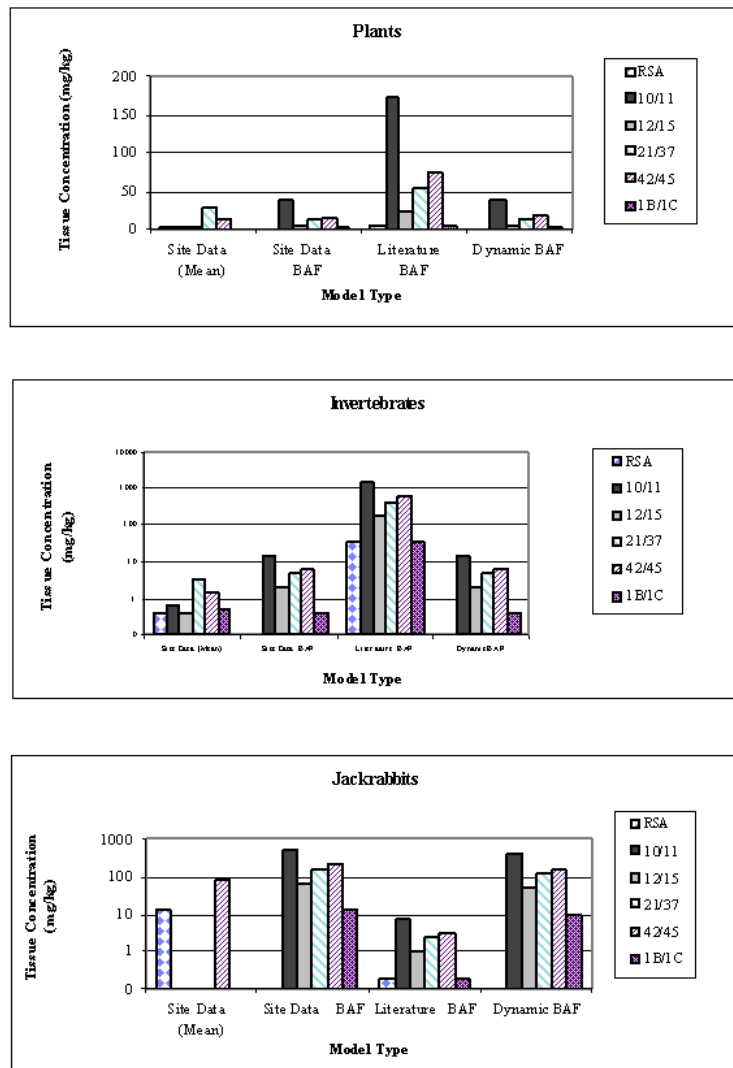


Figure 3. Comparisons Of Lead Tissue Concentrations By Model Type

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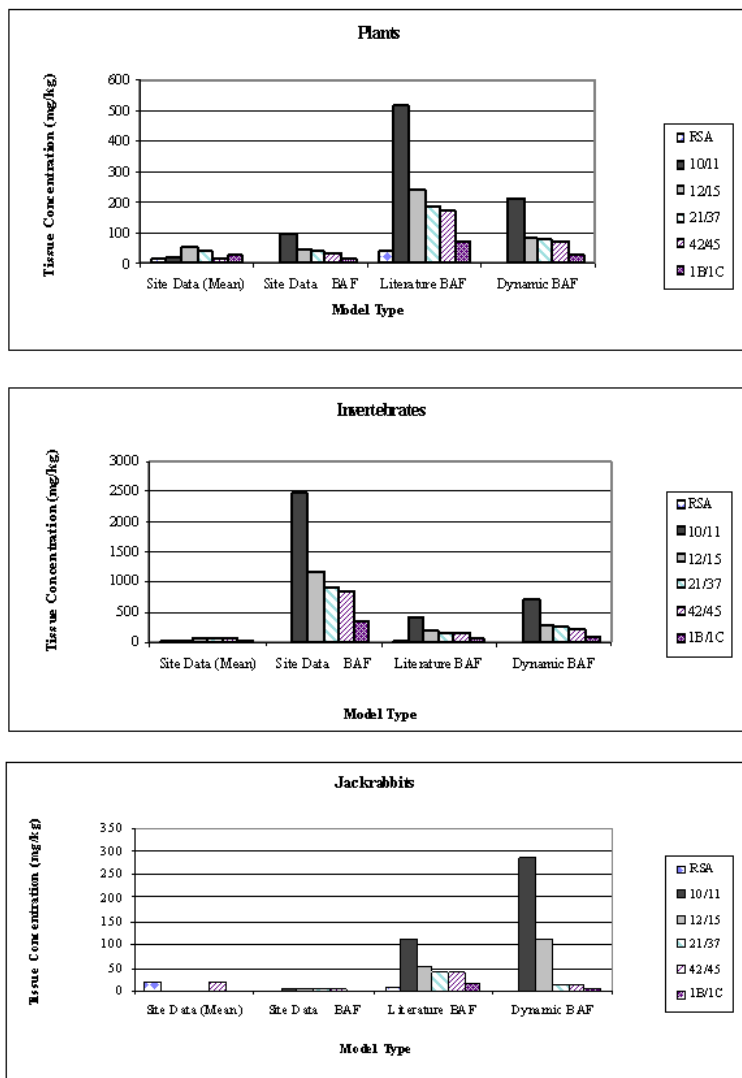


Figure 4. Comparisons Of Zinc Tissue Concentrations By Model Type