APPENDIX A

Harding ESE Office Memorandum: Plant Uptake of Metals at Fort Ord Site 39

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Subject: Fort Ord Prescribed Burn Air SAP

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This memorandum describes the methods and results of estimating concentrations of metals in plant tissue from concentrations in surface soil at Fort Ord, Site 39. Because direct measurements of metal concentrations in plant tissue were not available at the Site, models were used to predict these concentrations.

METHODOLOGY

Concentrations in plant tissue are typically modeled from soil concentrations using empirical models incorporating soil-plant uptake factors (PUFs). A PUF is the ratio of the concentration of a chemical in a plant (or portion thereof) to that in soil. For each chemical, the plant tissue concentration is derived by multiplying the soil concentration by the chemical-specific PUF. There are many uncertainties, using PUFs, however, including environmental factors and other sources of variability that are not incorporated in the model. Soil properties that affect concentrations of inorganic compounds in soil include pH, clay content, and organic matter. Because inorganic compounds (in addition to required nutrients) in soil water are passively taken up by plants, soil properties can have a great affect on how much of a chemical is absorbed into the plant tissue.

To account for many of these uncertainties, a regression equation was developed in *Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants* (*Bechtel Jacobs, 1998*). This equation is a regression of natural log (ln)-transformed plant concentration on ln-transformed soil concentration:

$$\ln(C_{plant}) = B0 + B1(\ln[C_{soil}])$$

where:

C_{plant} = Chemical concentration in plant tissue
C_{soil} = Chemical concentration in soil
B0/B1= Chemical-specific factors.

This regression equation was used in the analysis for all metals detected at the Site and evaluated in the Bechtel Jacobs (*1998*) study. For those metals detected at the Site but not analyzed in the Bechtel Jacobs (*1998*) study, PUFs were applied, as described below.

SITE DATA

Soil samples collected for the Remedial Investigation/Feasibility Study at Site 39 were used in this assessment (*HLA, 1995*). Samples were collected from areas expected to be highly impacted by ordnance (e.g., soil near targets). These areas include the high impact area and several ranges in the northern portion of the Site. Surface soil data (0 to 2 feet below ground surface) were compiled for this assessment because chemicals in deeper soils are not expected to be readily taken up by the roots of plants. Additionally, concentrations of metals in soil at Site 39 are higher in surface soils. A statistical data summary for metals detected in surface soil at the Site is presented in Table 1 and includes the following values: number of detections, number of analyses, frequency of detection, minimum detected value, maximum detected value, arithmetic mean, standard deviation, and 95 percent upper confidence limit on the arithmetic mean (95% UCL).

For comparative purposes, background data collected from 0 to 2 feet bgs were also included in the assessment. The 95% UCL background concentrations were compiled from the *Draft Final Basewide Background Soil Investigation, Fort Ord, California* (*HLA, 1993*). Background samples representing the NQTP soil type (i.e., not from the Paso Robles Formation) were used to represent the soil type at Site 39. The background 95% UCL concentrations are presented on Table 2. Because the Site 95% UCL concentration for mercury exceeds the background concentration, mercury in surface soil at the Site is likely within the range of background concentrations.

Antimony and selenium were not detected in the Site background samples. Detection limits for these chemicals ranged from 5.3 to 6.4 mg/kg for antimony and 0.5 to 0.61 mg/kg for selenium. In this analysis, half of the maximum detection limit for each chemical was used as a surrogate concentration for background (Table 2). For antimony, the half-detection limit concentration of 3.2 mg/kg exceeds the range of statewide background concentrations for antimony of 0.15 to 1.95 mg/kg from *Background Concentrations of Trace and Major Elements in California Soils* (*Bradford et al., 1996*). For selenium, the range of statewide background concentrations is 0.015 to 0.43 mg/kg; the half-detection limit concentration of 0.31 mg/kg used in this assessment is within this range.

Aluminum was not analyzed in soil samples at Fort Ord because it is the most commonly occurring metal in soil and is a major component of almost all common inorganic soil particles. However, aluminum is also a major component of ordnance and explosive compounds and, therefore, could be present in Site 39 soils at elevated concentrations. Aluminum is not soluble or bioavailable in soils with a pH range of 5.5 to 8.0 (*Sparling and Lowe, 1996*). Soil pH at Site 39 ranges from 4.7 to 7.7; therefore, it is likely that the majority of aluminum in Site 39 soils is not biologically available. However, background concentrations of aluminum in soil were included in the analysis. A statewide background 95% UCL concentration for aluminum was obtained from Bradford et al. (*1996*) and is presented in Table 2.

RESULTS

Concentrations in plant tissues were modeled from the 95% UCL concentrations in Site and background soils using the methodology described above (Table 2). Parameters for the regression equation were available for arsenic, cadmium, copper, lead, nickel, selenium, and zinc (*Bechtel Jacobs, 1998*). For these compounds, plant tissue concentrations were estimating using the regression analysis. For aluminum, antimony, beryllium, chromium, and silver, regression parameters were not available; thus, plant tissue concentrations were derived by multiplying the 95% UCL concentration by the PUF for each chemical. PUF values were compiled from the National Council on Radiation Protection Measurement (NCRPM; *1989*) for antimony, chromium, and silver and from Baes et al. (*1984*) for aluminum and beryllium. These PUFs are listed in the Toxicity and Chemical-Specific Factors Data Base (*ORNL, 2000*).

The Site and background modeled plant tissue concentrations for each chemical are presented in Table 2. These concentrations represent concentrations of metals in the foliage or stems of plants. The concentrations of compounds in fruits, seeds, or roots of plants are expected to be different because plants typically bioaccumulate inorganic elements to a different extent in these components. However, for purposes of this evaluation, which is related to the assessment of chemical concentrations in smoke from burning of vegetation, plant foliage and stems represent the majority of the burned material. Thus, the concentrations calculated using this method are appropriate for the intended use.

MODEL VALIDATION

In order to assess whether the regression and PUF models were accurate predictors of plant tissue concentrations at the Site, differences between modeled and actual measured background concentrations were assessed. Only the background data were compared because actual plant tissue data are not available for the Site. Table 3 presents modeled background concentrations and measured concentrations of metals in plants collected at reference areas of Fort Ord (*HLA, 1995*). Plant tissue data collected from reference areas for central maritime chapparal, coast live oak woodland, and upland ruderal species were selected because these species are present at the Site and would potentially be subject to burning. As shown in Table 3, all modeled concentrations are within the range of measured concentrations (for each chemical detected in the reference samples). Also, for antimony, beryllium, mercury, selenium, and silver, plant tissue concentrations for background are modeled although the chemicals were not detected in actual reference samples. These results indicate that the plant tissue concentrations modeled in this assessment are likely good or conservative estimators of actual plant tissue concentrations at the Site.

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Table 1. Statistical Data Summary of Metals Detected in Surface Soil
Prescribed Burn Air SAP
Site 39
Fort Ord, California

Metal	Number of Detections	Number of Analyses	Frequency of Detection (%)	Minimum Detected Value (mg/kg)	Maximum Detected Value (mg/kg)	Arithmetic Mean (mg/kg)	Standard Deviation (mg/kg)	95% UCL (mg/kg)
Antimony	48	223	21.5	0.46	100	1.87	7.83	17.2
Arsenic	167	221	75.6	0.46	10.5	1.46	1.13	3.68
Beryllium	59	218	27.1	0.12	66.9	0.47	4.52	9.34
Cadmium	40	218	18.4	0.93	104	3.06	12.2	26.9
Chromium	212	219	96.8	3.7	380	15.1	29.0	71.9
Copper	100	220	45.5	0.49	12900	138	941	1984
Lead	231	233	99.1	1.1	4060	88.4	381	836
Mercury	3	218	1.4	0.05	0.08	0.03	0.01	0.05
Nickel	157	218	72.0	4.9	344	10.7	25.1	59.9
Selenium	6	220	2.7	0.55	1.0	0.42	0.11	0.63
Silver	9	218	4.1	0.38	12.3	0.37	0.99	2.32
Zinc	140	218	64.2	5.2	8910	109	674	1430

% Percent.
mg/kg Milligrams per kilogram.
95% UCL 95 Percent upper confidence limit on the arithmetic mean.

Note: Data from *Basewide Remedial Investigation/Feasibility Study, Fort Ord, California* (*HLA, 1995*).
Only samples collected from 0 to 2 feet below ground surface were used.

Table 2. Modeled Concentrations of Metals in Plant Tissue
Prescribed Burn Air SAP
Site 39
Fort Ord, California

Metal	95% UCL Concentration in Site Surface Soil (C_{soil}) (mg/kg) [a]	95% UCL Concentration in Background Surface Soil ($C_{soilbck}$) (mg/kg) [b]	Regression Equation Parameters [c] B0	Regression Equation Parameters [c] B1	Plant Uptake Factor (PUF) [d]	Site Concentration in Plant Tissue (C_{plant}) (mg/kg) [e]	Background Concentration in Plant Tissue ($C_{plantbck}$) (mg/kg) [e]
Aluminum	--	77,000	--	--	0.004	--	308
Antimony	17.2	3.2	--	--	0.05	0.86	0.16
Arsenic	3.68	1.52	-1.992	0.564	--	0.28	0.17
Beryllium	9.34	0.15	--	--	0.01	0.09	0.001
Cadmium	26.9	0.45	-0.476	0.546	--	3.75	0.40
Chromium	71.9	12.7	--	--	0.04	2.88	0.51
Copper	1984	4.96	0.669	0.394	--	38.9	3.67
Lead	836	12.1	-1.328	0.561	--	11.5	1.07
Mercury	0.05	0.06	-0.996	0.544	--	0.07	0.08
Nickel	59.9	10.7	-2.224	0.748	--	2.31	0.64
Selenium	0.63	0.31	-0.678	1.104	--	0.30	0.14
Silver	2.32	0.19	--	--	1	2.32	0.19
Zinc	1430	19.4	1.575	0.555	--	272	25.0

95% UCL 95 Percent upper confidence limit on the arithmetic mean.
mg/kg Milligrams per kilogram.
ND Not detected.
-- Not available/applicable.

[a] From: Table 1.

[b] From: *Draft Final Basewide Background Soil Investigation, Fort Ord, California* (*HLA, 1993*). Only shallow NQTP (i.e., not derived from the Paso Robles Formation) soil samples applied to this assessment because NQTP is the soil type at Site 39. For antimony and selenium which were not detected, half of the maximum detection limit is presented. For aluminum, statewide background level from *Background Concentrations of Trace and Major Elements in California Soils* (*Bradford et al., 1996*) is presented.

[c] From: *Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants* (*Bechtel Jacobs, 1998*).

Regression Equation:

$\ln(C_{plant}) = B0 + B1(\ln[C_{soil}])$

where concentrations (mg/kg) are expressed on a dry-weight basis.

[d] From: Toxicity and Chemical-Specific Factors Data Base (*ORNL, 2000*). Soil-to-dry PUFs used in this assessment.

[e] C_{plant} estimated by the regression equation for arsenic, cadmium, copper, lead, nickel, selenium, and zinc. For antimony, beryllium, chromium, and silver, C_{plant} estimated by multiplying C_{soil} by the PUF.

Table 3. Comparison of Modeled and Measured Plant Tissue Concentrations
Prescribed Burn Air SAP
Site 39
Fort Ord, California

Metal	Modeled Concentration in Plant Tissue for Background ($C_{plantbck}$) (mg/kg) [a]	Measured Concentration in Plant Tissue at Reference Areas (mg/kg) [b]
Aluminum	308	--
Antimony	0.16	ND
Arsenic	0.17	0.12 - 0.3
Beryllium	0.001	ND
Cadmium	0.40	ND - 0.52
Chromium	0.51	ND - 0.7
Copper	3.67	1 - 8.1
Lead	1.07	0.18 - 3.5
Mercury	0.08	ND
Nickel	0.64	ND - 2.2
Selenium	0.14	ND
Silver	0.19	ND
Zinc	25.0	13.8 - 68.1

mg/kg Milligrams per kilogram.
-- Not available.
ND Not detected.

[a] From: Table 2.

[b] From: *HLA, 1995.* Data for central maritime chapparal, coast live oak woodland, and upland ruderal used.