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Technical Memorandum: Former ASARCO East Helena Facility Human Health Risk Assessment Updates

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PREPARED FOR:	Cindy Brooks/GETG
COPY TO:	Lauri Gorton/GETG
PREPARED BY:	CH2M
DATE:	December 15, 2017

This technical memorandum presents the final human health risk assessment (HHRA) for the former ASARCO East Helena site (Facility) in East Helena, Montana. The HHRA is required in accordance with the First Modification to the 1998 Resource Conservation and Recovery Act (RCRA) Consent Decree (Dreher, 2012) for the Facility. The HHRA was conducted using data collected to date at areas representative of site conditions (i.e., not remediated through excavation or covers) and by consolidating the results from the *Screening-Level Human Health Risk Assessment* (CH2M HILL, 2011), presented as Appendix B in the *Former ASARCO East Helena Facility Corrective Measures Study Work Plan* (CMS Work Plan) (CH2M HILL, 2015).

Methodology

The methodology for preparation of this assessment is consistent with the guidelines for preparing site-specific risk assessments as described in the following sources:

- USEPA's Risk Assessment Guidance for Superfund, including recent U.S. Environmental Protection Agency (USEPA) guidance for assessing lead in soil at Superfund sites and guidance for Regional Screening Levels (RSLs) in soil (USEPA, 1989; USEPA, 1991; USEPA, 2003; USEPA, 2016a; USEPA, 2016b; USEPA, 2016c)
- USEPA's Advanced Notice of Proposed Rulemaking for RCRA Corrective Action (USEPA, 1996)

Portions of the quantitative risk assessment prepared for the Superfund cleanup of the East Helena site were incorporated into the development of media cleanup standards (MCSs). A detailed description of that methodology is presented in the East Helena Superfund Site Operable Unit (OU) 2 Record of Decision (OU-2 ROD) (USEPA, 2009). Information presented in the OU-2 ROD was used to support identification of constituents of concern in soil and sediment.

Additionally, the Interstate Technology Regulatory Council's (ITRC) *Technical and Regulatory Guidance on Incremental Sampling Methodology* (ITRC, 2012) was used to identify the appropriate upper confidence limit (UCL) for exposure point concentrations (EPC).

As detailed in the *Former ASARCO East Helena Facility Corrective Measures Study Report* (CH2M, 2017) for the Facility (CH2M, 2017), risks associated with potential exposures at Parcels 2, 3, 4, 6, 7, 9, 13, 14, the portion of Parcel 8 located east of Highway 518 (8E), and Parcels 21 and 22 were evaluated in the OU-2 ROD (USEPA, 2009). For these "undeveloped lands" parcels, the goal of this final risk assessment was simply to identify whether or not that evaluation remains current and complete. For the remaining "CMS Parcels" (i.e., Parcels 10, 11, 12, 15, 16, 17, 18, 19, 23, the portion of 8 located west of State Highway 518 [8W], and portions of Parcel 2 near Prickly Pear Creek [PPC; Parcel 2a]), the goal was to evaluate potential risks to support corrective measures study (CMS) evaluations. Corrective actions

including excavation of contaminated media and backfilling or covering with soil containing concentrations of constituents of concern (arsenic and lead) lower than MCSs are complete or ongoing at Parcels 8W, 10, 11, 12, 16, 17, 18, and 19. Therefore, this final risk assessment focused on Parcels 2a, 15, and 23.

Summary of Exposure Pathways

The constituents of concern for assessing risks to human health through exposures to soil and sediment are primarily arsenic and lead. Both the *Screening-Level Human Health Risk Assessment* (CH2M HILL, 2011) and the OU-2 ROD (USEPA, 2009) identified several constituents in soil or sediment with concentrations higher than screening levels, including arsenic, cadmium, chromium, lead, mercury, selenium, and thallium, but also noted that the constituents with the widest distribution and highest concentrations in surface soil or sediment were arsenic and lead. For the OU-2 ROD, USEPA concluded that lead was the primary constituent of concern; arsenic was also identified as a constituent of concern, but considered to pose lower risk (USEPA, 2009). USEPA noted that once areas were cleaned up to remove arsenic and lead, potential exposures to the other constituents were further minimized. As a result, this risk assessment focused on arsenic and lead concentrations in surface soil and sediment. Arsenic, cadmium, and selenium concentrations were also evaluated for subsurface soils in Parcel 2a, which have the potential to impact groundwater through leaching. Risks for constituents of concern were not quantitatively evaluated, rather EPCs were compared to USEPA maximum contaminant level (MCL)-based soil screening levels (SSLs; USEPA, 2016a) in order to evaluate soil concentrations needed to achieve MCLs in groundwater.

Exposure scenarios were developed to provide estimates of Reasonable Maximum Exposure (RME) to constituents in surface (0 to 2 feet below ground surface [bgs]) and subsurface (2 to 12 feet bgs) soil or sediment. Scenarios based on RME assumptions estimate potential exposures which are well above average exposures but less than maximum exposures (USEPA, 1989). Currently anticipated land uses and human activities potentially on the parcels are based on the most recent City of East Helena zoning ordinance from December 2016. For purposes of this evaluation, current and future land uses are assumed to be the same. The City of East Helena including the former smelter site and surrounding parcels fall within an institutional control boundary with land use controls administered by the Lewis and Clark County Health Department (USEPA, 2009). Risks from constituents in groundwater have been addressed by comparing concentrations in groundwater with drinking water standards such as MCLs and therefore, risk was not quantified for groundwater constituents of concern. The exposure scenarios for the CMS Parcels addressed in this assessment are as follows:

- Parcel 2a: commercial/industrial use for soil; recreational use for surface soil and sediment along the PPC corridor through the parcel
- Parcel 15: commercial/industrial use for soil
- Parcel 23: commercial/industrial use for soil; recreational use for sediment

For both commercial/industrial and recreational uses, the potential exposure pathways considered for surface soils and sediments were incidental ingestion, dermal exposure, and for surface soil, inhalation of dust suspended into the air. Conceptual models of exposure pathways for these three parcels are presented on **Figures 1, 2,** and **3** for Parcels 2a, 15, and 23, respectively; these conceptual models provide a full description of the potential exposure pathways to humans from potentially affected media as well as the pathways considered to be potentially complete.

Risk Characterization

Potential risks were quantitatively evaluated for CMS Parcels not undergoing corrective action (i.e., Parcels 2a, 15, and 23) using the approach and methods detailed in this section. For the undeveloped

lands parcels evaluated in the OU-2 ROD (USEPA, 2009), potential risks were qualitatively evaluated by comparing MCSs applied at the time to those used in this final risk assessment. If the MCSs utilized in the OU-2 ROD are the same, or lower, than those identified for this evaluation, the assumption was made that the conclusions of that risk evaluation were complete and are applicable to this evaluation.

Data Summary and Exposure Point Concentrations

Soil and sediment data included in this evaluation comprise:

- 2016 incremental surface soil samples collected in Parcels 2a, 15, and 23 (Table 3-6 of the CMS; CH2M, 2017)
- Discrete subsurface soil samples collected in Parcel 2a in 2008 (Table 3-7 of the CMS; CH2M, 2017)
- Discrete sediment samples from Parcels 2a and 23 (Table 3-7 of the CMS; CH2M, 2017)

Simple summary statistics, including the number of samples, frequency of detection, and minimum and maximum detected and nondetected results, are provided, per parcel and medium, in **Table 1** (located at the end of this technical memorandum). UCLs and EPCs are also provided in **Table 1**. EPCs are estimated upper-bound average concentrations to which a receptor may be exposed. For the purposes of the evaluation, the EPC is defined as the minimum of either the maximum detected concentration or the 95 percent UCL on the arithmetic mean calculated using the USEPA statistical software package ProUCL 5.0.00 (USEPA, 2013). Different approaches were taken to identify the UCL selected for reporting (i.e., EPCs and comparison to MCSs) for discrete and incremental samples. For discrete samples, the UCL recommended by the ProUCL software was selected; for incremental samples, the appropriate UCL was identified based on ITRC's 2012 guidance on incremental sampling methodology (ISM) (ITRC, 2012).

ITRC states the following, "Two candidate UCL equations that can accommodate ISM data sets and which are expected to "bracket" the range of UCLs that may be calculated from a data set are the Student's-t (representing the low end of the range) and Chebyshev (representing the high end of the range) UCLs." With regard to the Chebyshev UCLs, which were selected for reporting in order to be conservative, ITRC guidance states, "The Chebyshev is generally considered to be a conservative estimate of the UCL because it generally achieves or exceeds the desired coverage rates, even for non-normal distributions." As a result, maximum available 95 percent Chebyshev UCL was selected. EPCs were then compared to associated MCSs to evaluate potential risks. ProUCL output for calculated UCLs are provided in the **Attachment** to this technical memorandum.

Media Cleanup Standards for Human Health

MCSs for the Facility were detailed in the CMS Work Plan (CH2M, 2015) and are summarized in Table 2-1 of the *Former ASARCO East Helena Facility Corrective Measures Study Report* (CH2M, 2017); values are also included in **Table 1** in comparison to EPCs. The basis for each standard and key considerations regarding the development of the MCSs include the following:

- The commercial/industrial MCS for lead in surface soil and sediment (800 milligrams per kilogram [mg/kg]) is based on the USEPA RSL (USEPA, 2017), which is being applied as MCSs at mining and smelter sites in Montana and across the country. The commercial/industrial MCS for lead was calculated using the calculated using the Adult Lead Model recommended by USEPA (USEPA, 2003) and is defined as the concentration in soil that yields a 95th percentile blood lead value of 10 micrograms per deciliter (µg/dL) in a developing fetus.
- The recreational MCS for lead in surface soil and sediment (3,245 mg/kg) was identified in the OU-2 ROD (USEPA, 2009) and was also calculated using the Adult Lead Model (USEPA, 2003) and a target of 10 µg/dL for no more than 5 percent of the exposed population.
- Both the commercial/industrial (572 mg/kg) and recreational (794 mg/kg) MCSs for arsenic in surface soil and sediment were identified in the OU-2 ROD (USEPA, 2009). These standards are

based on carcinogenic toxicity criteria published in the USEPA RSLs (USEPA, 2016a) and a target risk equal to 1.499 x 10^{-4}, which was deemed to fall within USEPA's target risk range of 1 x 10^{-6} to 1 x 10^{-4} (i.e., is less than 2 x 10^{-4}; USEPA, 2007).

- USEPA's protection of groundwater SSLs are identified as the MCSs for constituents of concern in subsurface soil to represent soil concentrations considered to be protective of groundwater. However, arsenic is naturally occurring at concentrations which exceed the MCL-based SSL of 0.29 mg/kg. As noted in the Montana Department of Environmental Quality (MDEQ) document, *Project Report Background Concentrations of Inorganic Constituents in Montana Surface Soils* (MDEQ, 2013), the mean soil concentration is 22.5 mg/kg and the report text cites a generic action level of 40 mg/kg for soil. The basis for the 40-mg/kg concentration is presented in the document titled *Montana Department of Environmental Quality Remediation Division Action Level for Arsenic in Surface Soil* (MDEQ, 2005), which states in Section 2.0, Data Summary and Action Level Calculation, "….*DEQ determined that the 95% UCL of 40 mg/kg represents an appropriate generic action level for arsenic because* ***it represents native soil concentrations that can reasonably be expected at most facilities***…" (emphasis added). Therefore, because a site-specific background level for arsenic has not been determined, the Custodial Trust proposes using 40 mg/kg as the MCS for arsenic, in subsurface soil to be protective of groundwater.

Calculation of Risk Estimates

Risk estimates were calculated for arsenic in surface soil and sediment using the risk ratio method for calculating risks using the MCSs (USEPA, 1989, 1991, 2016b). This calculation method is detailed separately in the following sections for carcinogenic and noncancer effects.

Carcinogenic Risk Estimate

The potential for carcinogenic effects were evaluated by estimating the excess lifetime carcinogenic risk (ELCR) for arsenic in surface soils and sediments (where applicable). The ELCR is the incremental increase in the probability of developing cancer during one's lifetime in addition to the background probability of developing cancer. For example, an individual exposed to a carcinogen with a calculated cancer risk of 2x10^{-4} indicates that the probability of the individual getting cancer increases by 2 per 10,000 exposed.

ELCRs were calculated using the risk ratio method described in the RSL guidance (USEPA, 2016b); the EPC was divided by the associated MCS for the cancer endpoint and multiplied by the corresponding target risk, as follows:

$$ELCR = (EPC \times TR)/MCS$$

Where:

EPC = 95 percent UCL concentration for COPC, or maximum detected concentration if it is less than the UCL (mg/kg)

TR = target risk (1.49 x 10^{-4}; USEPA, 2009)

MCS = media cleanup standard (mg/kg)

Noncarcinogenic Hazard Estimate

Potential noncancer health effects were evaluated by the calculation of a hazard index (HI).

The HI for arsenic was calculated using a risk ratio method (USEPA, 1991); the EPC was divided by the associated MCS based on the noncancer endpoint, as follows:

$$HI = EPC/MCS$$

Where:

EPC = 95 percent UCL concentration for COPC, or maximum detected concentration if it is less than the UCL (mg/kg)

MCS = media cleanup standard based on a target HI of 1 (mg/kg)

An HI greater than 1 indicates there is some potential for adverse noncarcinogenic health effects associated with exposure to the constituent of concern.

Lead

Assessing potential risks related to exposure to lead is unique because a reference dose (RfD) is not available. Typically derived from a concentration below which no adverse effects have been observed, this approach is not suitable for lead because adverse health effects occur even at very low exposures. Because the toxicokinetics (the absorption, distribution, metabolism, and excretion of toxins in the body) of lead (Pb) are well understood, lead is regulated based on blood lead concentration (PbB) and the associated media concentrations that would lead to threshold PbB values. As a result, risk estimates are not calculated as is done for arsenic. Instead, lead EPCs are simply compared to the applicable MCSs to determine the potential need for corrective action.

Results and Conclusions

The HHRA found no areas with risks to human health that are not being addressed with corrective measures. However, human health risks to groundwater may be present in areas where the MCLs are exceeded and private wells are used.

As shown in **Table 1**, human health risks associated with arsenic in soil and sediment in the parcels assessed (Parcels 2a, 15, and 23) are estimated to fall within USEPA's target cancer risk range of 1×10^{-6} to 1×10^{-4}. Concentrations of lead in soil and sediment in these parcels are estimated to be lower than USEPA's current blood-lead target level of 10 µg/dL. The EPC for lead in surface soil in Parcel 2a is estimated to be less than concentrations associated with a blood-lead level of 10 µg/dL. Therefore, this result may not indicate that corrective measures are warranted. The MCS for lead for a commercial/industrial scenario is 800 mg/kg, which was developed using USEPA's Adult Lead Model (USEPA, 2003) and has been the RSL (USEPA, 2016a) for several years. However, the RSL has not kept pace with revisions to the Adult Lead Model, which was updated in 2009 and provided a screening level of 2,240 mg/kg corresponding to a blood-lead level of 10 µg/dL.

In 2016, USEPA published another update to the Adult Lead Model, which updates the screening level to 2,737 mg/kg corresponding to a 10 µg/dL blood-lead level (USEPA, 2016c). The OU-2 ROD includes a cleanup level for lead in soil of 1,482 mg/kg, also based on a blood-lead level of 10 µg/dL. In addition, based on site-specific data from the East Helena site consisting of paired blood lead/soil lead concentration data indicated that soil lead concentrations ranging from 1,000 to 1,500 mg/kg did not influence blood-lead levels (USEPA, 2009). Based on these multiple lines of evidence, it is plausible that a lead concentration in soil higher than 800 mg/kg may not be associated with a blood-lead level higher than 10 µg/dL.

With respect to subsurface soils and the potential to impact groundwater; while the EPC for arsenic is less than the MCS based on the generic background value (MDEQ, 2005; MDEQ, 2013), the EPCs for cadmium and selenium are greater than the associated MCSs based on USEPA groundwater protection SSLs. No additional corrective measures are required, however, as institutional controls are currently in place to prevent groundwater use.

Lastly, with respect to the undeveloped lands (Parcels 2, 3, 4, 6, 7, 9, 13, 14, 8E, 21, and 22), the goal of this final risk assessment was simply to identify whether or not the risk assessment detailed in the OU-2 ROD remains current and complete. This was completed by comparing MCSs applied in the OU-2 ROD to those used in this final risk assessment. The results of this comparison identify that the MCSs utilized in the OU-2 ROD are the same, or lower, than those applied in this evaluation with the exception of the

commercial/industrial MCS for lead in surface soil (1,482 mg/kg per the OU-2 ROD compared to 800 mg/kg applied in this risk assessment). As previously stated, however, there is a range of screening criteria (800 to 2,737 mg/kg) that can be considered when evaluating a commercial/industrial exposure scenario and the OU-2 ROD value of 1,482 mg/kg is well within this range. Therefore, it is assumed that the conclusions of the risk assessment presented in the OU-2 ROD were complete and are currently applicable.[1]

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[1] The geographic scope of the OU-2 ROD encompassed parcels 2, 3, 4, 6, 7, 9, 13, 14, 8E, 21, and 22.

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U.S. Environmental Protection Agency (USEPA). 2016c. *Transmittal of Update to the Adult Lead Methodology's Default Baseline Blood Lead Concentration and Geometric Standard Deviation Parameters*. Memorandum to Superfund National Program Managers, Regions 1 – 10 from Dana Stalcup, Director Assessment and Remediation Division Office of Superfund Remediation and Technology Innovation. August 2.

Table

Table 1. Former ASARCO East Helena Facility Final Risk Assessment Results

Parcel	Medium	Depth Grouping	Applicable Exposure Scenario	Sampling Method	Analyte	# of Samples	FOD	Unit	Range of NDs	Min. Detect	Max. Detect	Mean Detect	Sample with Max. Detect	EPC (mg/kg)	EPC Basis	Commercial/ Industrial MCS (mg/kg)	Recreational MCS (mg/kg)	EPC Excxeeds MCS?	Notes	Arsenic Risk
2a	Sediment	Surface	Recreational	Discrete	Arsenic	11	11 / 11	mg/kg	na	12	54	28.64	2a-2-SD	45.47	95% Chebyshev (MVUE) UCL	na	794	no	EPC < MCS	8.6E-06
2a	Sediment	Surface		Discrete	Lead	11	11 / 11	mg/kg	na	83	402	177.9	2a-2-SD	306.2	95% Chebyshev(Mean, Sd) UCL		3,245	no	EPC < MCS	--
2a	Soil	Surface	Commerical/ Industrial & Recreational	ISM	Arsenic	31	31 / 31	mg/kg	na	21	246	86	P2a-DU1	133.5	95% Chebyshev (MVUE) UCL	572	794	no	EPC < MCSs	2.5E-05
2a	Soil	Surface		ISM	Lead	31	31 / 31	mg/kg	na	142	2,390	788.5	P2a-DU1	1169	95% Chebyshev (MVUE) UCL	800	3,245	yes	EPC > Commercial/Industrial MCS; Refer to "Results and Conclusions" section of the text.	--
2a	Soil	Subsurface	Leaching to groundwater	Discrete	Arsenic	6	5 / 6	mg/kg	5 - 5	5.2	31.8	22.66	EH-121-03	29.8	95% KM (t) UCL	40*		no	EPC < MCS	--
2a	Soil	Subsurface		Discrete	Cadmium	6	6 / 6	mg/kg	na	2.8	7.3	4.15	EH-67-03	5.53	95% Student's-t UCL	0.38*		no	EPC > MCS; Institutional controls are in place to protect against groundwater use.	--
2a	Soil	Subsurface		Discrete	Selenium	6	6 / 6	mg/kg	na	18.8	49.7	34.88	EH-66-02	44.52	95% Student's-t UCL	0.26*		no		--
15	Soil	Surface	Commercial/ Industrial	ISM	Arsenic	23	23 / 23	mg/kg	na	25	109	46.39	P15-DUA3	64.07	95% Chebyshev(Mean, Sd) UCL	572	na	no	EPC < MCS	1.7E-05
15	Soil	Surface		ISM	Lead	23	23 / 23	mg/kg	na	237	2,020	596.1	P15-DU3	1,028	95% Chebyshev(Mean, Sd) UCL	800		no	EPC < MCS	--
23	Sediment	Surface	Recreational	Discrete	Arsenic	5	5 / 5	mg/kg	na	10	25	17.8	23-1-SD	29.91	95% Chebyshev (MVUE) UCL	na	794	no	EPC < MCS	5.6E-06
23	Sediment	Surface		Discrete	Lead	5	5 / 5	mg/kg	na	47	152	104.6	23-4-SD	204	95% Chebyshev (MVUE) UCL		3,245	no	EPC < MCS	--
23	Soil	Surface	Commercial/ Industrial	ISM	Arsenic	32	32 / 32	mg/kg	na	29	87	56.83	P23-DU4	69.31	95% Chebyshev(Mean, Sd) UCL	572	na	no	EPC < MCS	1.8E-05
23	Soil	Surface		ISM	Lead	32	32 / 32	mg/kg	na	185	621	374.7	P23-DU4	465.2	95% Chebyshev (MVUE) UCL	800		no	EPC < MCS	--

Notes:

* MCSs presented for comparison to subsurface soil concentrations represent USEPA Regional Screening Levels for soil for protection of groundwater (USEPA, 2016a).

EPC = exposure point concentration. Note that the maximum Chebyshev-based UCL was selected as the EPC for ISM samples (ITRC, 2012) and the maximum recommended UCL was selected for discrete samples.

ISM = incremental sampling methodology

MCS = media cleanup standard; see Table 2-1 of the *Former ASARCO East Helena Facility Corrective Measures Study Report* (CH2M, 2017) for values and the basis for each.

mg/kg = milligrams per kilogram

MVUE = Mean Value Unbiased Estimate

na = not applicable

ND = nondetect

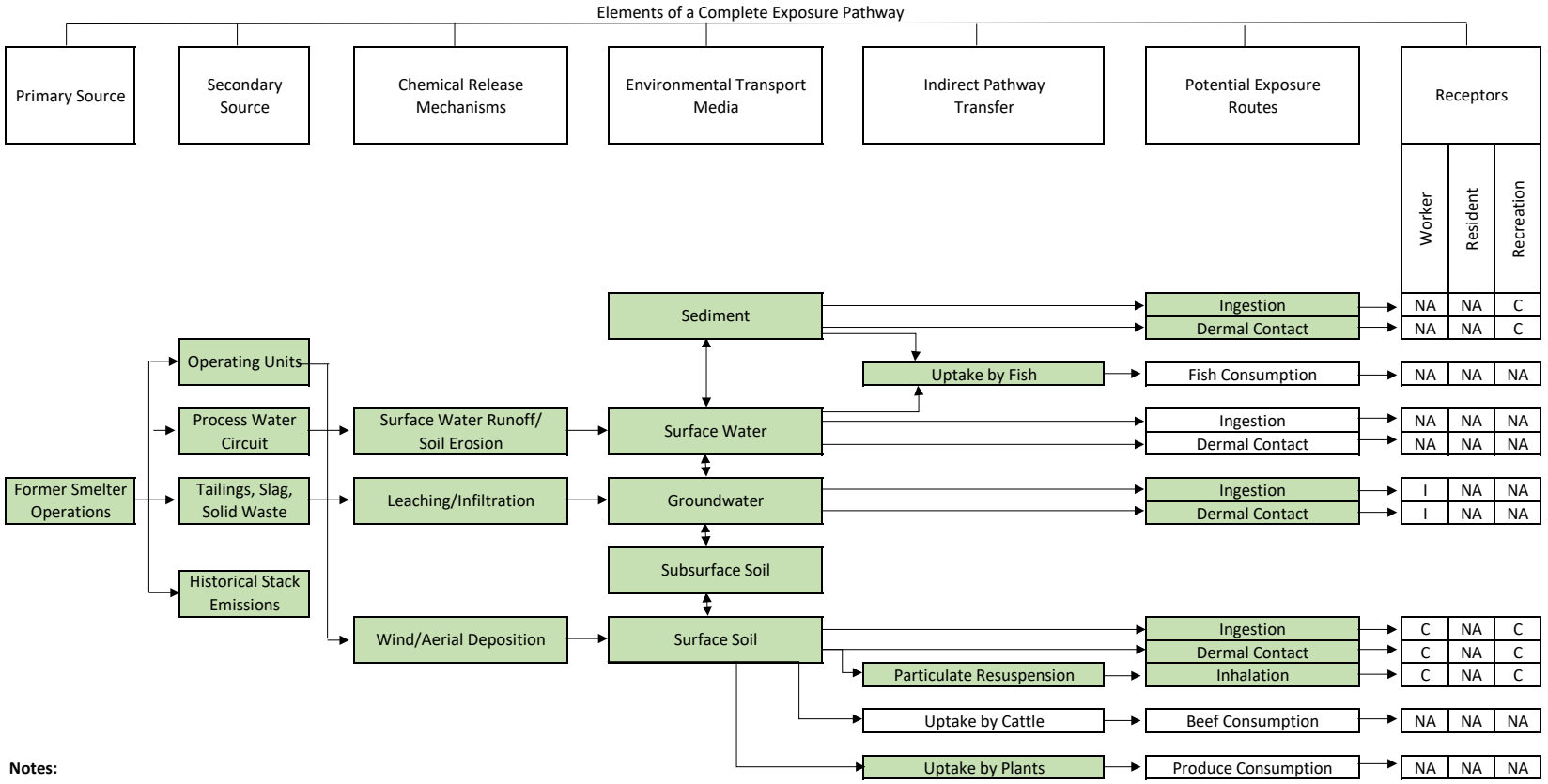
RSL = Regional Screening Level

Subsurface = greater than 2 feet below ground surface

Surface = 0 to 2 feet below ground surface

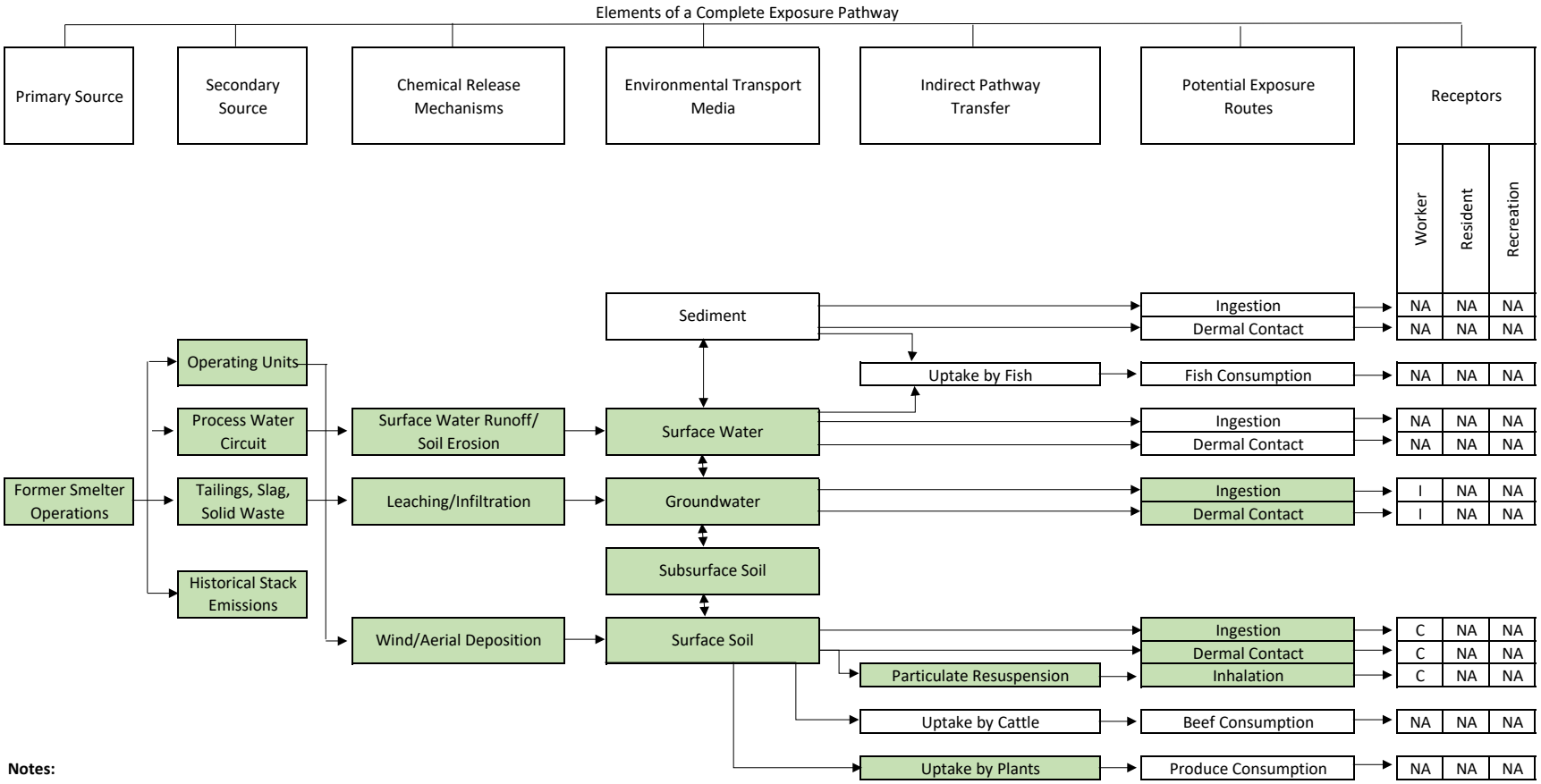
UCL = Upper Confidence Limit

Figures



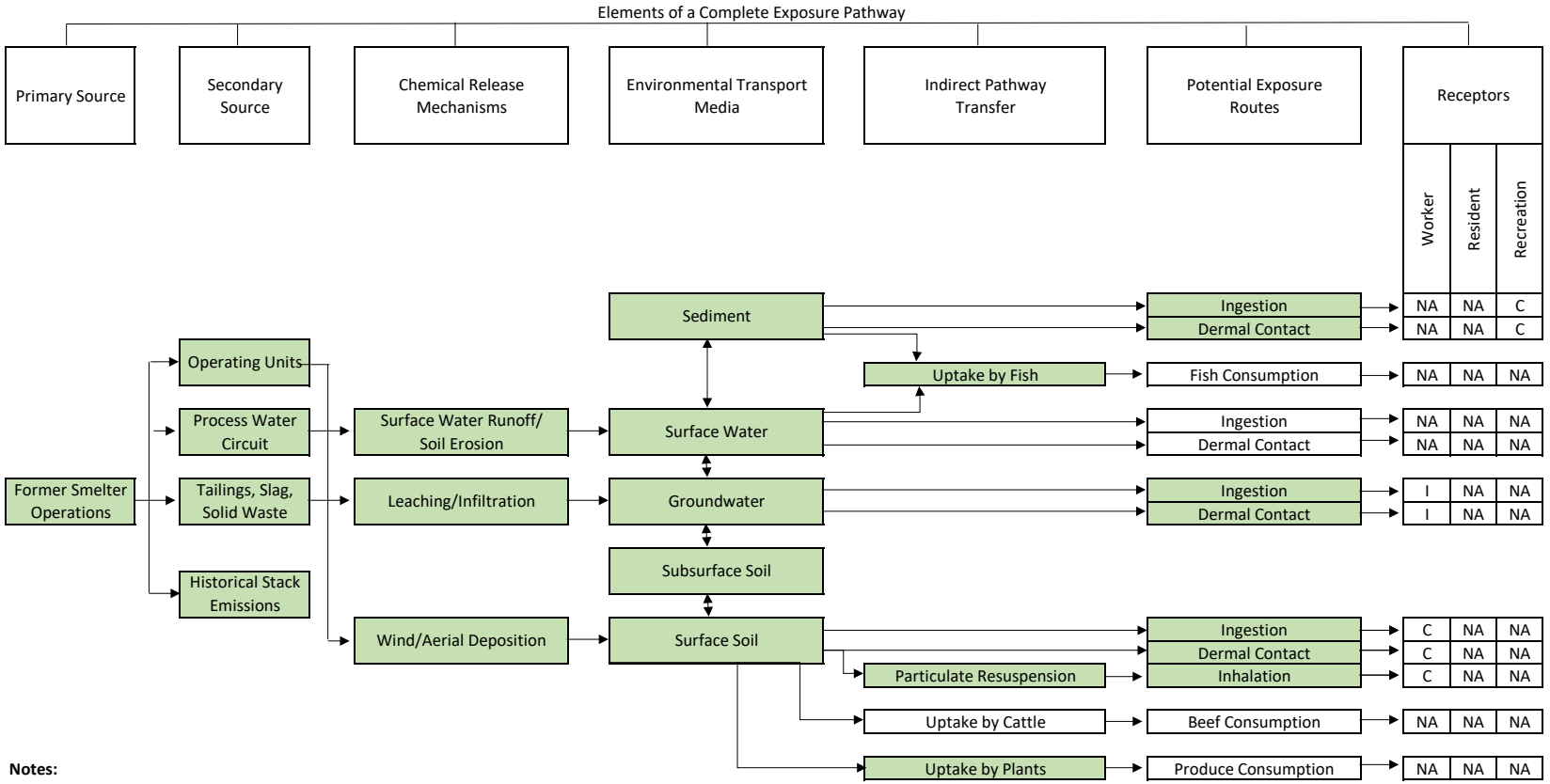
Notes:
C = Potentially Complete Pathway I = Incomplete Pathway
NA = not an applicable pathway
Green-shaded boxes indicate potentially applicable elements of exposure pathways.

Figure 1
Conceptual Exposure Model for Potential Human Receptors - Parcel 2a (Former Smelter Site)
East Helena, Montana



Notes:
C = Potentially Complete Pathway
I = Incomplete Pathway
NA = not an applicable pathway
Green-shaded boxes indicate potentially applicable elements of exposure pathways.

Figure 2
Conceptual Exposure Model for Potential Human Receptors - Parcel 15 (Former Smelter Site)
East Helena, Montana



Notes:
C = Potentially Complete Pathway I = Incomplete Pathway
NA = not an applicable pathway
Green-shaded boxes indicate potentially applicable elements of exposure pathways.

Figure 3
Conceptual Exposure Model for Potential Human Receptors - Parcel 23 (Former Smelter Site)
East Helena, Montana

Attachment
Output for Calculated Upper Confidence Limit

UCL Statistics for Data Sets with Nondetects

User Selected Options	
Date/Time of Computation	11/28/2016 3:48:07 PM
From File	ProUCLInput_CMSParcelsDiscrete.xls
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

2aSub-Arsenic

General Statistics

Total Number of Observations	6	Number of Distinct Observations	6
Number of Detects	5	Number of Nondetects	1
Number of Distinct Detects	5	Number of Distinct Nondetects	1
Minimum Detect	5.2	Minimum Nondetect	5
Maximum Detect	31.8	Maximum Nondetect	5
Variance Detects	115.3	Percent Nondetects	16.67%
Mean Detects	22.66	SD Detects	10.74
Median Detects	27.8	CV Detects	0.474
Skewness Detects	-1.419	Kurtosis Detects	1.598
Mean of Logged Detects	2.955	SD of Logged Detects	0.752

Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest. For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012). Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.0

Normal GOF Test on Detects Only

Shapiro Wilk Test Statistic	0.856	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.762	Detected Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.284	**Lilliefors GOF Test**

5% Lilliefors Critical Value	0.396	Detected Data appear Normal at 5% Significance Level

Detected Data appear Normal at 5% Significance Level

Kaplan-Meier (KM) Statistics using Normal Critical Values and other Nonparametric UCLs

Mean	19.72	Standard Error of Mean	5.004
SD	10.96	95% KM (BCA) UCL	26.37
95% KM (t) UCL	29.8	95% KM (Percentile Bootstrap) UCL	26.95
95% KM (z) UCL	27.95	95% KM Bootstrap t UCL	26.92
90% KM Chebyshev UCL	34.73	95% KM Chebyshev UCL	41.53
97.5% KM Chebyshev UCL	50.97	99% KM Chebyshev UCL	69.51

Gamma GOF Tests on Detected Observations Only

A-D Test Statistic	0.663	**Anderson-Darling GOF Test**
5% A-D Critical Value	0.682	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.313	**Kolmogrov-Smirnoff GOF**
5% K-S Critical Value	0.359	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics on Detected Data Only

k hat (MLE)	3.173	k star (bias corrected MLE)	1.403
Theta hat (MLE)	7.141	Theta star (bias corrected MLE)	16.16
nu hat (MLE)	31.73	nu star (bias corrected)	14.03
MLE Mean (bias corrected)	22.66	MLE Sd (bias corrected)	19.13

Gamma Kaplan-Meier (KM) Statistics

k hat (KM)	3.234	nu hat (KM)	38.81
Approximate Chi Square Value (38.81, α)	25.54	Adjusted Chi Square Value (38.81, β)	21.74
95% Gamma Approximate KM-UCL (use when n>=50)	29.96	95% Gamma Adjusted KM-UCL (use when n<50)	35.2

Gamma ROS Statistics using Inputted Nondetects

GROS may not be used when data set has > 50% NDs with many tied observations at multiple DLs

GROS may not be used when kstar of detected data is small such as < 0.1

For such situations, GROS method tends to yield inflated values of UCLs and BTVs

For gamma distributed detected data, BTVs and UCLs may be computed using gamma distribution on KM estimates

Minimum	4.827	Mean	19.69
Maximum	31.8	Median	23.75
SD	12.05	CV	0.612
k hat (MLE)	2.11	k star (bias corrected MLE)	1.166
Theta hat (MLE)	9.329	Theta star (bias corrected MLE)	16.88
nu hat (MLE)	25.32	nu star (bias corrected)	14
MLE Mean (bias corrected)	19.69	MLE Sd (bias corrected)	18.23
		Adjusted Level of Significance (β)	0.0122
Approximate Chi Square Value (14.00, α)	6.568	Adjusted Chi Square Value (14.00, β)	4.85
95% Gamma Approximate UCL (use when n>=50)	41.95	95% Gamma Adjusted UCL (use when n<50)	56.81

Lognormal GOF Test on Detected Observations Only

Shapiro Wilk Test Statistic	0.741	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.762	Detected Data Not Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.314	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.396	Detected Data appear Lognormal at 5% Significance Level	

Detected Data appear Approximate Lognormal at 5% Significance Level

Lognormal ROS Statistics Using Inputted Nondetects

Mean in Original Scale	19.52	Mean in Log Scale	2.686
SD in Original Scale	12.3	SD in Log Scale	0.941
95% t UCL (assumes normality of ROS data)	29.64	95% Percentile Bootstrap UCL	26.77
95% BCA Bootstrap UCL	25.64	95% Bootstrap t UCL	27.91
95% H-UCL (Log ROS)	118.5		

UCLs using Lognormal Distribution and KM Estimates when Detected data are Lognormally Distributed

KM Mean (logged)	2.731	95% H-UCL (KM -Log)	71.49
KM SD (logged)	0.793	95% Critical H Value (KM-Log)	3.454
KM Standard Error of Mean (logged)	0.362		

DL/2 Statistics

DL/2 Normal **DL/2 Log-Transformed**

Mean in Original Scale	19.3	Mean in Log Scale	2.615
SD in Original Scale	12.65	SD in Log Scale	1.07
95% t UCL (Assumes normality)	29.71	95% H-Stat UCL	196.5

DL/2 is not a recommended method, provided for comparisons and historical reasons

Nonparametric Distribution Free UCL Statistics

Detected Data appear Normal Distributed at 5% Significance Level

Suggested UCL to Use

95% KM (t) UCL	29.8	95% KM (Percentile Bootstrap) UCL	26.95

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
Recommendations are based upon data size, data distribution, and skewness.
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).
However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.

2aSub-Cadmium

General Statistics

Total Number of Observations	6	Number of Distinct Observations	6
		Number of Missing Observations	0
Minimum	2.8	Mean	4.15
Maximum	7.3	Median	3.65
SD	1.681	Std. Error of Mean	0.686
Coefficient of Variation	0.405	Skewness	1.672

Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use
guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest.
For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012).
Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.0

Normal GOF Test

Shapiro Wilk Test Statistic	0.825	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.788	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.228	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.362	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	5.533	95% Adjusted-CLT UCL (Chen-1995)	5.78
		95% Modified-t UCL (Johnson-1978)	5.611

Gamma GOF Test

A-D Test Statistic	0.404	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.698	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.195	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.333	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	8.843	k star (bias corrected MLE)	4.533
Theta hat (MLE)	0.469	Theta star (bias corrected MLE)	0.916
nu hat (MLE)	106.1	nu star (bias corrected)	54.39
MLE Mean (bias corrected)	4.15	MLE Sd (bias corrected)	1.949
		Approximate Chi Square Value (0.05)	38.45
Adjusted Level of Significance	0.0122	Adjusted Chi Square Value	33.67

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	5.871	95% Adjusted Gamma UCL (use when n<50)	6.704

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.902	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.788	Data appear Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.173	**Lilliefors Lognormal GOF Test**

5% Lilliefors Critical Value	0.362	Data appear Lognormal at 5% Significance Level

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	1.03	Mean of logged Data	1.366
Maximum of Logged Data	1.988	SD of logged Data	0.357

Assuming Lognormal Distribution

95% H-UCL	6.055	90% Chebyshev (MVUE) UCL	5.933
95% Chebyshev (MVUE) UCL	6.75	97.5% Chebyshev (MVUE) UCL	7.885
99% Chebyshev (MVUE) UCL	10.11		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	5.279	95% Jackknife UCL	5.533
95% Standard Bootstrap UCL	5.183	95% Bootstrap-t UCL	7.723
95% Hall's Bootstrap UCL	10.32	95% Percentile Bootstrap UCL	5.25
95% BCA Bootstrap UCL	5.633		
90% Chebyshev(Mean, Sd) UCL	6.209	95% Chebyshev(Mean, Sd) UCL	7.142
97.5% Chebyshev(Mean, Sd) UCL	8.437	99% Chebyshev(Mean, Sd) UCL	10.98

Suggested UCL to Use

95% Student's-t UCL	5.533

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

2aSub-Selenium

General Statistics

Total Number of Observations	6	Number of Distinct Observations	6
		Number of Missing Observations	0
Minimum	18.8	Mean	34.88
Maximum	49.7	Median	32.7
SD	11.71	Std. Error of Mean	4.781
Coefficient of Variation	0.336	Skewness	0.0459

Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest.
For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012).
Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.0

Normal GOF Test

Shapiro Wilk Test Statistic	0.945	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.788	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.192	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.362	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	44.52	95% Adjusted-CLT UCL (Chen-1995)	42.84
		95% Modified-t UCL (Johnson-1978)	44.53

Gamma GOF Test

A-D Test Statistic	0.274	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.698	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.188	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.332	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	9.935	k star (bias corrected MLE)	5.078
Theta hat (MLE)	3.511	Theta star (bias corrected MLE)	6.869
nu hat (MLE)	119.2	nu star (bias corrected)	60.94
MLE Mean (bias corrected)	34.88	MLE Sd (bias corrected)	15.48
		Approximate Chi Square Value (0.05)	43.99
Adjusted Level of Significance	0.0122	Adjusted Chi Square Value	38.84

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	48.33	95% Adjusted Gamma UCL (use when n<50)	54.73

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.939	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.788	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.185	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.362	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	2.934	Mean of logged Data	3.501
Maximum of Logged Data	3.906	SD of logged Data	0.359

Assuming Lognormal Distribution

95% H-UCL	51.45	90% Chebyshev (MVUE) UCL	50.34
95% Chebyshev (MVUE) UCL	57.31	97.5% Chebyshev (MVUE) UCL	66.98
99% Chebyshev (MVUE) UCL	85.97		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	42.75	95% Jackknife UCL	44.52
95% Standard Bootstrap UCL	42.31	95% Bootstrap-t UCL	46.76

95% Hall's Bootstrap UCL	46.03	95% Percentile Bootstrap UCL	42.42
95% BCA Bootstrap UCL	42.23		
90% Chebyshev(Mean, Sd) UCL	49.23	95% Chebyshev(Mean, Sd) UCL	55.73
97.5% Chebyshev(Mean, Sd) UCL	64.74	99% Chebyshev(Mean, Sd) UCL	82.46

Suggested UCL to Use

95% Student's-t UCL	44.52

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

UCL Statistics for Data Sets with Nondetects

User Selected Options	
Date/Time of Computation	12/1/2016 6:48:58 PM
From File	ProUCLInput_SurfaceSoilISM2016.xls
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

23-Arsenic

General Statistics

Total Number of Observations	32	Number of Distinct Observations	26
		Number of Missing Observations	0
Minimum	29	Mean	56.83
Maximum	87	Median	57.5
SD	14.56	Std. Error of Mean	2.574
Coefficient of Variation	0.256	Skewness	-0.0736

Normal GOF Test

Shapiro Wilk Test Statistic	0.978	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.93	Data appear Normal at 5% Significance Level	
Lilliefors Test Statistic	0.0889	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.157	Data appear Normal at 5% Significance Level	

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	61.19	95% Adjusted-CLT UCL (Chen-1995)	61.03
		95% Modified-t UCL (Johnson-1978)	61.19

Gamma GOF Test

A-D Test Statistic	0.383	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.746	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.123	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.155	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	14.41	k star (bias corrected MLE)	13.08
Theta hat (MLE)	3.943	Theta star (bias corrected MLE)	4.344
nu hat (MLE)	922.3	nu star (bias corrected)	837.2
MLE Mean (bias corrected)	56.83	MLE Sd (bias corrected)	15.71
		Approximate Chi Square Value (0.05)	771
Adjusted Level of Significance	0.0416	Adjusted Chi Square Value	767.6

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	61.7	95% Adjusted Gamma UCL (use when n<50)	61.98

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.948	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.93	Data appear Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.142	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.157	Data appear Lognormal at 5% Significance Level

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.367	Mean of logged Data	4.005
Maximum of Logged Data	4.466	SD of logged Data	0.278

Assuming Lognormal Distribution

95% H-UCL	62.32	90% Chebyshev (MVUE) UCL	65.45
95% Chebyshev (MVUE) UCL	69.31	97.5% Chebyshev (MVUE) UCL	74.65
99% Chebyshev (MVUE) UCL	85.15		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	61.06	95% Jackknife UCL	61.19
95% Standard Bootstrap UCL	61.07	95% Bootstrap-t UCL	61.1
95% Hall's Bootstrap UCL	60.97	95% Percentile Bootstrap UCL	60.92
95% BCA Bootstrap UCL	60.93		
90% Chebyshev(Mean, Sd) UCL	64.55	95% Chebyshev(Mean, Sd) UCL	68.05
97.5% Chebyshev(Mean, Sd) UCL	72.91	99% Chebyshev(Mean, Sd) UCL	82.44

Suggested UCL to Use

95% Student's-t UCL	61.19

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Note: For highly negatively-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

23-Lead

General Statistics

Total Number of Observations	32	Number of Distinct Observations	31
		Number of Missing Observations	0
Minimum	185	Mean	374.7
Maximum	621	Median	376.5
SD	106.8	Std. Error of Mean	18.87
Coefficient of Variation	0.285	Skewness	0.104

Normal GOF Test

Shapiro Wilk Test Statistic	0.981	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.93	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.0643	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.157	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	406.7	95% Adjusted-CLT UCL (Chen-1995)	406.1
		95% Modified-t UCL (Johnson-1978)	406.7

Gamma GOF Test

A-D Test Statistic	0.275	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.746	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.0926	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.155	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	11.88	k star (bias corrected MLE)	10.79
Theta hat (MLE)	31.54	Theta star (bias corrected MLE)	34.73
nu hat (MLE)	760.3	nu star (bias corrected)	690.4
MLE Mean (bias corrected)	374.7	MLE Sd (bias corrected)	114.1
		Approximate Chi Square Value (0.05)	630.4
Adjusted Level of Significance	0.0416	Adjusted Chi Square Value	627.4

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	410.3	95% Adjusted Gamma UCL (use when n<50)	412.3

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.961	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.93	Data appear Lognormal at 5% Significance Level

Lilliefors Test Statistic	0.104	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.157	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	5.22	Mean of logged Data	5.883
Maximum of Logged Data	6.431	SD of logged Data	0.305

Assuming Lognormal Distribution

95% H-UCL	415	90% Chebyshev (MVUE) UCL	437.3
95% Chebyshev (MVUE) UCL	465.2	97.5% Chebyshev (MVUE) UCL	504.1
99% Chebyshev (MVUE) UCL	580.3		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	405.7	95% Jackknife UCL	406.7
95% Standard Bootstrap UCL	405.4	95% Bootstrap-t UCL	405.3
95% Hall's Bootstrap UCL	406.6	95% Percentile Bootstrap UCL	405
95% BCA Bootstrap UCL	405.9		
90% Chebyshev(Mean, Sd) UCL	431.3	95% Chebyshev(Mean, Sd) UCL	456.9
97.5% Chebyshev(Mean, Sd) UCL	492.5	99% Chebyshev(Mean, Sd) UCL	562.5

Suggested UCL to Use

95% Student's-t UCL	406.7

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

2a-Arsenic

General Statistics

Total Number of Observations	31	Number of Distinct Observations	24
		Number of Missing Observations	0
Minimum	21	Mean	86
Maximum	246	Median	92
SD	51.89	Std. Error of Mean	9.319
Coefficient of Variation	0.603	Skewness	1.37

Normal GOF Test

Shapiro Wilk Test Statistic	0.859	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.929	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.166	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.159	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	101.8	95% Adjusted-CLT UCL (Chen-1995)	103.8
		95% Modified-t UCL (Johnson-1978)	102.2

Gamma GOF Test

A-D Test Statistic	0.925	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.753	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.158	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.159	Detected data appear Gamma Distributed at 5% Significance Level

Detected data follow Appr. Gamma Distribution at 5% Significance Level

Gamma Statistics

k hat (MLE)	2.944	k star (bias corrected MLE)	2.681
Theta hat (MLE)	29.21	Theta star (bias corrected MLE)	32.08
nu hat (MLE)	182.5	nu star (bias corrected)	166.2

MLE Mean (bias corrected)	86	MLE Sd (bias corrected)	52.53
		Approximate Chi Square Value (0.05)	137.4
Adjusted Level of Significance	0.0413	Adjusted Chi Square Value	135.9

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50)	104	95% Adjusted Gamma UCL (use when n<50)	105.1

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.92	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.929	Data Not Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.192	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.159	Data Not Lognormal at 5% Significance Level	

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.045	Mean of logged Data	4.275
Maximum of Logged Data	5.505	SD of logged Data	0.634

Assuming Lognormal Distribution

95% H-UCL	111.3	90% Chebyshev (MVUE) UCL	119
95% Chebyshev (MVUE) UCL	133.5	97.5% Chebyshev (MVUE) UCL	153.5
99% Chebyshev (MVUE) UCL	192.8		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	101.3	95% Jackknife UCL	101.8
95% Standard Bootstrap UCL	101.2	95% Bootstrap-t UCL	105.7
95% Hall's Bootstrap UCL	108.7	95% Percentile Bootstrap UCL	101.2
95% BCA Bootstrap UCL	103.2		
90% Chebyshev(Mean, Sd) UCL	114	95% Chebyshev(Mean, Sd) UCL	126.6
97.5% Chebyshev(Mean, Sd) UCL	144.2	99% Chebyshev(Mean, Sd) UCL	178.7

Suggested UCL to Use

95% Adjusted Gamma UCL 105.1

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

2a-Lead

General Statistics

Total Number of Observations	31	Number of Distinct Observations	31
		Number of Missing Observations	0
Minimum	142	Mean	788.5
Maximum	2390	Median	666
SD	485.4	Std. Error of Mean	87.18
Coefficient of Variation	0.616	Skewness	1.871

Normal GOF Test

Shapiro Wilk Test Statistic	0.828	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.929	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.182	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.159	Data Not Normal at 5% Significance Level	

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	936.5	95% Adjusted-CLT UCL (Chen-1995)	963.2
		95% Modified-t UCL (Johnson-1978)	941.4

Gamma GOF Test

A-D Test Statistic	0.441	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.752	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.107	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.159	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	3.326	k star (bias corrected MLE)	3.026
Theta hat (MLE)	237	Theta star (bias corrected MLE)	260.6
nu hat (MLE)	206.2	nu star (bias corrected)	187.6
MLE Mean (bias corrected)	788.5	MLE Sd (bias corrected)	453.3
		Approximate Chi Square Value (0.05)	156.9
Adjusted Level of Significance	0.0413	Adjusted Chi Square Value	155.4

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50)	942.7	95% Adjusted Gamma UCL (use when n<50)	952.2

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.976	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.929	Data appear Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.118	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.159	Data appear Lognormal at 5% Significance Level

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	4.956	Mean of logged Data	6.512
Maximum of Logged Data	7.779	SD of logged Data	0.578

Assuming Lognormal Distribution

95% H-UCL	981.6	90% Chebyshev (MVUE) UCL	1051
95% Chebyshev (MVUE) UCL	1169	97.5% Chebyshev (MVUE) UCL	1333
99% Chebyshev (MVUE) UCL	1655		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	931.9	95% Jackknife UCL	936.5
95% Standard Bootstrap UCL	923.5	95% Bootstrap-t UCL	1002
95% Hall's Bootstrap UCL	1043	95% Percentile Bootstrap UCL	940.9
95% BCA Bootstrap UCL	971.9		
90% Chebyshev(Mean, Sd) UCL	1050	95% Chebyshev(Mean, Sd) UCL	1169
97.5% Chebyshev(Mean, Sd) UCL	1333	99% Chebyshev(Mean, Sd) UCL	1656

Suggested UCL to Use

95% Adjusted Gamma UCL	952.2

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

15-Arsenic

General Statistics

Total Number of Observations	23	Number of Distinct Observations	17
		Number of Missing Observations	0
Minimum	25	Mean	46.39
Maximum	109	Median	37
SD	19.46	Std. Error of Mean	4.057
Coefficient of Variation	0.419	Skewness	1.673

Normal GOF Test

Shapiro Wilk Test Statistic	0.843	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.914	Data Not Normal at 5% Significance Level	

Lilliefors Test Statistic	0.207	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.185	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	53.36	95% Adjusted-CLT UCL (Chen-1995)	54.58
		95% Modified-t UCL (Johnson-1978)	53.59

Gamma GOF Test

A-D Test Statistic	0.692	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.745	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.205	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.182	Data Not Gamma Distributed at 5% Significance Level

Detected data follow Appr. Gamma Distribution at 5% Significance Level

Gamma Statistics

k hat (MLE)	7.332	k star (bias corrected MLE)	6.405
Theta hat (MLE)	6.327	Theta star (bias corrected MLE)	7.243
nu hat (MLE)	337.3	nu star (bias corrected)	294.6
MLE Mean (bias corrected)	46.39	MLE Sd (bias corrected)	18.33
		Approximate Chi Square Value (0.05)	255.9
Adjusted Level of Significance	0.0389	Adjusted Chi Square Value	253.2

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50)	53.42	95% Adjusted Gamma UCL (use when n<50)	53.97

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.943	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.914	Data appear Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.196	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.185	Data Not Lognormal at 5% Significance Level

Data appear Approximate Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.219	Mean of logged Data	3.767
Maximum of Logged Data	4.691	SD of logged Data	0.368

Assuming Lognormal Distribution

95% H-UCL	53.63	90% Chebyshev (MVUE) UCL	57.04
95% Chebyshev (MVUE) UCL	61.96	97.5% Chebyshev (MVUE) UCL	68.8
99% Chebyshev (MVUE) UCL	82.23		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	53.06	95% Jackknife UCL	53.36
95% Standard Bootstrap UCL	53.05	95% Bootstrap-t UCL	56.17
95% Hall's Bootstrap UCL	57.11	95% Percentile Bootstrap UCL	53.22
95% BCA Bootstrap UCL	55		
90% Chebyshev(Mean, Sd) UCL	58.56	95% Chebyshev(Mean, Sd) UCL	64.07
97.5% Chebyshev(Mean, Sd) UCL	71.73	99% Chebyshev(Mean, Sd) UCL	86.76

Suggested UCL to Use

95% Adjusted Gamma UCL	53.97

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

15-Lead

General Statistics

Total Number of Observations	23	Number of Distinct Observations	23
		Number of Missing Observations	0
Minimum	237	Mean	596.1
Maximum	2020	Median	410
SD	474.8	Std. Error of Mean	99
Coefficient of Variation	0.796	Skewness	2.257

Normal GOF Test

Shapiro Wilk Test Statistic	0.684	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.914	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.285	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.185	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	766.1	95% Adjusted-CLT UCL (Chen-1995)	808.7
		95% Modified-t UCL (Johnson-1978)	773.8

Gamma GOF Test

A-D Test Statistic	1.356	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.752	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.237	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.183	Data Not Gamma Distributed at 5% Significance Level

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	2.654	k star (bias corrected MLE)	2.337
Theta hat (MLE)	224.6	Theta star (bias corrected MLE)	255.1
nu hat (MLE)	122.1	nu star (bias corrected)	107.5
MLE Mean (bias corrected)	596.1	MLE Sd (bias corrected)	389.9
		Approximate Chi Square Value (0.05)	84.56
Adjusted Level of Significance	0.0389	Adjusted Chi Square Value	83.09

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	757.7	95% Adjusted Gamma UCL (use when n<50)	771.1

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.892	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.914	Data Not Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.194	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.185	Data Not Lognormal at 5% Significance Level	

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	5.468	Mean of logged Data	6.19
Maximum of Logged Data	7.611	SD of logged Data	0.592

Assuming Lognormal Distribution

95% H-UCL	753.6	90% Chebyshev (MVUE) UCL	801.1
95% Chebyshev (MVUE) UCL	902.9	97.5% Chebyshev (MVUE) UCL	1044
99% Chebyshev (MVUE) UCL	1322		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	758.9	95% Jackknife UCL	766.1
95% Standard Bootstrap UCL	754.5	95% Bootstrap-t UCL	936.4
95% Hall's Bootstrap UCL	1565	95% Percentile Bootstrap UCL	764
95% BCA Bootstrap UCL	812.3		
90% Chebyshev(Mean, Sd) UCL	893.1	95% Chebyshev(Mean, Sd) UCL	1028
97.5% Chebyshev(Mean, Sd) UCL	1214	99% Chebyshev(Mean, Sd) UCL	1581

Suggested UCL to Use

95% Chebyshev (Mean, Sd) UCL	1028

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.

These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)

and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.

For additional insight the user may want to consult a statistician.

UCL Statistics for Data Sets with Nondetects

User Selected Options	
Date/Time of Computation	11/22/2016 9:42:59 AM
From File	Data_a.xls
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

2a-Arsenic

General Statistics

Total Number of Observations	11	Number of Distinct Observations	9
		Number of Missing Observations	0
Minimum	12	Mean	28.64
Maximum	54	Median	26
SD	12.64	Std. Error of Mean	3.812
Coefficient of Variation	0.442	Skewness	0.859

Normal GOF Test

Shapiro Wilk Test Statistic	0.921	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.85	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.183	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.267	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	35.55	95% Adjusted-CLT UCL (Chen-1995)	35.96
		95% Modified-t UCL (Johnson-1978)	35.71

Gamma GOF Test

A-D Test Statistic	0.287	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.731	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.172	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.256	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	5.917	k star (bias corrected MLE)	4.364
Theta hat (MLE)	4.84	Theta star (bias corrected MLE)	6.563
nu hat (MLE)	130.2	nu star (bias corrected)	96
MLE Mean (bias corrected)	28.64	MLE Sd (bias corrected)	13.71
		Approximate Chi Square Value (0.05)	74.4
Adjusted Level of Significance	0.0278	Adjusted Chi Square Value	71.3

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	36.95	95% Adjusted Gamma UCL (use when n<50)	38.55

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.968	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.85	Data appear Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.149	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.267	Data appear Lognormal at 5% Significance Level

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	2.485	Mean of logged Data	3.268
Maximum of Logged Data	3.989	SD of logged Data	0.44

Assuming Lognormal Distribution

95% H-UCL	38.72	90% Chebyshev (MVUE) UCL	40.22
95% Chebyshev (MVUE) UCL	45.47	97.5% Chebyshev (MVUE) UCL	52.75
99% Chebyshev (MVUE) UCL	67.04		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	34.91	95% Jackknife UCL	35.55
95% Standard Bootstrap UCL	34.46	95% Bootstrap-t UCL	37.81
95% Hall's Bootstrap UCL	39.3	95% Percentile Bootstrap UCL	34.55
95% BCA Bootstrap UCL	35.64		
90% Chebyshev(Mean, Sd) UCL	40.07	95% Chebyshev(Mean, Sd) UCL	45.25
97.5% Chebyshev(Mean, Sd) UCL	52.44	99% Chebyshev(Mean, Sd) UCL	66.57

Suggested UCL to Use

95% Student's-t UCL	35.55

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

23-Arsenic

General Statistics

Total Number of Observations	5	Number of Distinct Observations	5
		Number of Missing Observations	0
Minimum	10	Mean	17.8
Maximum	25	Median	19
SD	5.63	Std. Error of Mean	2.518
Coefficient of Variation	0.316	Skewness	-0.259

Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest. For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012).

Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.0

Normal GOF Test

Shapiro Wilk Test Statistic	0.985	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.762	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.184	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.396	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	23.17	95% Adjusted-CLT UCL (Chen-1995)	21.63
		95% Modified-t UCL (Johnson-1978)	23.12

Gamma GOF Test

A-D Test Statistic	0.243	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.679	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.226	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.358	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	11.21	k star (bias corrected MLE)	4.618
Theta hat (MLE)	1.588	Theta star (bias corrected MLE)	3.855
nu hat (MLE)	112.1	nu star (bias corrected)	46.18
MLE Mean (bias corrected)	17.8	MLE Sd (bias corrected)	8.283
		Approximate Chi Square Value (0.05)	31.59
Adjusted Level of Significance	0.0086	Adjusted Chi Square Value	26.42

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	26.02	95% Adjusted Gamma UCL (use when n<50)	31.11

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.949	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.762	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.225	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.396	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	2.303	Mean of logged Data	2.834
Maximum of Logged Data	3.219	SD of logged Data	0.348

Assuming Lognormal Distribution

95% H-UCL	28.01	90% Chebyshev (MVUE) UCL	26.15
95% Chebyshev (MVUE) UCL	29.91	97.5% Chebyshev (MVUE) UCL	35.13
99% Chebyshev (MVUE) UCL	45.38		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	21.94	95% Jackknife UCL	23.17
95% Standard Bootstrap UCL	21.5	95% Bootstrap-t UCL	22.91
95% Hall's Bootstrap UCL	21.65	95% Percentile Bootstrap UCL	21.6
95% BCA Bootstrap UCL	21.4		
90% Chebyshev(Mean, Sd) UCL	25.35	95% Chebyshev(Mean, Sd) UCL	28.78
97.5% Chebyshev(Mean, Sd) UCL	33.52	99% Chebyshev(Mean, Sd) UCL	42.85

Suggested UCL to Use

95% Student's-t UCL	23.17

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Note: For highly negatively-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

2a-Lead

General Statistics

Total Number of Observations	11	Number of Distinct Observations	11
		Number of Missing Observations	0
Minimum	83	Mean	177.9
Maximum	402	Median	139
SD	97.61	Std. Error of Mean	29.43
Coefficient of Variation	0.549	Skewness	1.461

Normal GOF Test

Shapiro Wilk Test Statistic	0.847	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.85	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.225	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.267	Data appear Normal at 5% Significance Level

Data appear Approximate Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	231.3	95% Adjusted-CLT UCL (Chen-1995)	240.2
		95% Modified-t UCL (Johnson-1978)	233.4

Gamma GOF Test

A-D Test Statistic	0.366	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.732	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.177	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.256	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	4.428	k star (bias corrected MLE)	3.281
Theta hat (MLE)	40.18	Theta star (bias corrected MLE)	54.22
nu hat (MLE)	97.42	nu star (bias corrected)	72.18
MLE Mean (bias corrected)	177.9	MLE Sd (bias corrected)	98.22
		Approximate Chi Square Value (0.05)	53.62
Adjusted Level of Significance	0.0278	Adjusted Chi Square Value	51.02

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	239.5	95% Adjusted Gamma UCL (use when n<50)	251.7

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.95	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.85	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.149	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.267	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	4.419	Mean of logged Data	5.064
Maximum of Logged Data	5.996	SD of logged Data	0.493

Assuming Lognormal Distribution

95% H-UCL	250.7	90% Chebyshev (MVUE) UCL	257
95% Chebyshev (MVUE) UCL	293.5	97.5% Chebyshev (MVUE) UCL	344
99% Chebyshev (MVUE) UCL	443.4		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	226.3	95% Jackknife UCL	231.3

95% Standard Bootstrap UCL	224.2	95% Bootstrap-t UCL	269.7
95% Hall's Bootstrap UCL	515.9	95% Percentile Bootstrap UCL	226.3
95% BCA Bootstrap UCL	244.2		
90% Chebyshev(Mean, Sd) UCL	266.2	95% Chebyshev(Mean, Sd) UCL	306.2
97.5% Chebyshev(Mean, Sd) UCL	361.7	99% Chebyshev(Mean, Sd) UCL	470.8

Suggested UCL to Use

95% Student's-t UCL 231.3

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

23-Lead

General Statistics

Total Number of Observations	5	Number of Distinct Observations	5
		Number of Missing Observations	0
Minimum	47	Mean	104.6
Maximum	152	Median	91
SD	45.49	Std. Error of Mean	20.34
Coefficient of Variation	0.435	Skewness	-0.016

Note: Sample size is small (e.g., <10), if data are collected using ISM approach, you should use guidance provided in ITRC Tech Reg Guide on ISM (ITRC, 2012) to compute statistics of interest. For example, you may want to use Chebyshev UCL to estimate EPC (ITRC, 2012). Chebyshev UCL can be computed using the Nonparametric and All UCL Options of ProUCL 5.0

Normal GOF Test

Shapiro Wilk Test Statistic	0.893	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.762	Data appear Normal at 5% Significance Level

Lilliefors Test Statistic	0.241	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.396	Data appear Normal at 5% Significance Level	

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	148	95% Adjusted-CLT UCL (Chen-1995)	137.9
		95% Modified-t UCL (Johnson-1978)	147.9

Gamma GOF Test

A-D Test Statistic	0.36	**Anderson-Darling Gamma GOF Test**	
5% A-D Critical Value	0.68	Detected data appear Gamma Distributed at 5% Significance Level	
K-S Test Statistic	0.256	**Kolmogrov-Smirnoff Gamma GOF Test**	
5% K-S Critical Value	0.358	Detected data appear Gamma Distributed at 5% Significance Level	

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	5.891	k star (bias corrected MLE)	2.49
Theta hat (MLE)	17.76	Theta star (bias corrected MLE)	42.01
nu hat (MLE)	58.91	nu star (bias corrected)	24.9
MLE Mean (bias corrected)	104.6	MLE Sd (bias corrected)	66.29
		Approximate Chi Square Value (0.05)	14.53
Adjusted Level of Significance	0.0086	Adjusted Chi Square Value	11.22

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	179.2	95% Adjusted Gamma UCL (use when n<50)	232

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.902	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.762	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.222	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.396	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.85	Mean of logged Data	4.563
Maximum of Logged Data	5.024	SD of logged Data	0.486

Assuming Lognormal Distribution

95% H-UCL	218.4	90% Chebyshev (MVUE) UCL	173.2
95% Chebyshev (MVUE) UCL	204	97.5% Chebyshev (MVUE) UCL	246.8
99% Chebyshev (MVUE) UCL	330.7		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	138.1	95% Jackknife UCL	148
95% Standard Bootstrap UCL	134.1	95% Bootstrap-t UCL	168.1
95% Hall's Bootstrap UCL	198.5	95% Percentile Bootstrap UCL	137.4
95% BCA Bootstrap UCL	130.6		
90% Chebyshev(Mean, Sd) UCL	165.6	95% Chebyshev(Mean, Sd) UCL	193.3
97.5% Chebyshev(Mean, Sd) UCL	231.6	99% Chebyshev(Mean, Sd) UCL	307

Suggested UCL to Use

95% Student's-t UCL	148

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Note: For highly negatively-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

Technical Memorandum: Assessment of Lead in Soil to Develop an Ecological Media Cleanup Standard for Passerines at the Former ASARCO East Helena Facility

Assessment of Lead in Soil for an Ecological Media Cleanup Standard for Passerines at the Former ASARCO East Helena Facility

PREPARED FOR:	Cindy Brooks/GETG
COPY TO:	Lauri Gorton/GETG
PREPARED BY:	CH2M
DATE:	December 15, 2017

In the *Former ASARCO East Helena Facility Corrective Measures Study Report* (CMS Report) (CH2M, 2017), lead is proposed as the primary indicator parameter for surface soil and a soil lead level of 650 milligrams per kilogram (mg/kg) is proposed as the media cleanup standard (MCS) considered protective of ecological receptors. The CMS Work Plan cites as the basis for this MCS the *Supplemental Ecological Risk Assessment for the East Helena Smelter Site* (USEPA, 2005), which states:

> *Based on the results of the Anaconda Smelter wildlife biomonitoring evaluation, it was concluded that the primary receptors of concern were insectivorous passerine species and the primary contaminant of concern was lead (Hoff, 2002). In addition, the Anaconda assessment determined that lead began accumulating in prey items and passerine tissues at levels of concern when bulk soil lead concentrations were above about 650 mg/kg (Hoff, 2002).*

The Baseline Ecological Risk Assessment (BERA) for the former ASARCO East Helena site (Facility) (Gradient, 2011) also cites this conclusion from the 2005 *Supplemental Ecological Risk Assessment*, but does not further analyze the results presented in *Wildlife Biomonitoring at the Anaconda Smelter Site, Deer Lodge County, Montana* (Anaconda Smelter study) (Hoff, 2002). In addition, the CMS Work Plan references conversations between the Custodial Trust and the U.S. Fish and Wildlife Service (USFWS) as a basis for proposing the 650 mg/kg lead concentration in soil as an ecological MCS.

The purpose of this technical memorandum is to summarize the findings of the Anaconda Smelter study, outline the basis for the 650 mg/kg MCS, and provide an assessment of lead concentrations at the Facility. The assessment includes a summary of songbird protection levels developed for the Coeur d'Alene (CDA) Basin Superfund site as a comparison to the MCS. Additionally, concentrations at corrective measures study (CMS) Parcels 2a and 15 are discussed relative to the ecological MCS and protective levels developed for CDA, and liver tissue concentrations modeled from soil lead concentrations at CMS Parcels 2a and 15 are compared to effect levels reported in literature sources.

Anaconda Smelter Wildlife Biomonitoring Study

The lead in soil MCS of 650 mg/kg for protection of passerine species was extracted from wildlife biomonitoring data collected from the Anaconda Smelter site in Montana and presented in the Anaconda Smelter study (Hoff, 2002). This 2-year biomonitoring study was conducted by Texas Tech University for USFWS. The study addressed a data need for evaluating the protectiveness of the selected remedy for the Anaconda site by (1) providing pertinent biological data to refine the conceptual models

of risks to wildlife used in the BERA (Gradient, 2011), and (2) identifying resource-efficient methods for long-term wildlife monitoring.

The chemicals of concern assessed in this study were arsenic, cadmium, copper, lead, and zinc in soil. A primary study objective was to quantify the level of exposure and effects for these analytes, and resultant risk, to wildlife at the Anaconda site by studying representative species inhabiting the site. This was accomplished through the measurement of arsenic and metals concentrations in wildlife blood and tissue, prey items and soil, and measurements of biomarkers of effect in blood and tissues. These values were compared with literature benchmarks for subclinical and clinical toxic effects. Nesting demographic data were also collected as a measure of effect.

Study Results for Passerines

The effects of metal and arsenic exposure in passerines (starlings, bluebirds, swallows, chickadees) were assessed using multiple biochemical endpoints: alterations in liver and kidney porphyrin profiles and inhibition of blood delta-aminolevulenic acid dehydrogenase (ALAD) activity along with measurements of effects on red blood cells (packed cell volume).[1] These represent sensitive biomarkers of metals exposure. Concentrations of metals in blood and tissues (liver and kidney) were compared with literature thresholds corresponding to subclinical, toxic, and lethal levels (Franson, 1996). Reproductive success over the course of 2 years was assessed by observing nest-box use, hatching, and fledging success and measuring the weights of birds on differing days following hatching (nestling morphology).

The biomonitoring study showed altered biomarker levels, characterized by elevated porphyrin levels and depressed ALAD blood levels, in birds inhabiting the sites with the highest metals concentrations in soil. The elevated porphyrin levels may have related to levels of multiple metals in soil and cannot be linked specifically with lead. Comparison of tissue lead concentrations and ALAD inhibition levels with literature-based hazard criteria indicated that a small proportion of individuals were exposed to potentially toxic lead levels. However, this exposure did not correspond to effects on red blood cell formation. Variation in packed cell volumes in birds were observed across all of the study sites, but these were not considered to be biologically significant. Studies of nesting demographics and nestling morphology concluded that, in general, reproductive demographics across the site for both years were within literature values. Metal and arsenic exposure and accumulation could not be statistically tied to adverse effects on reproduction of starlings inhabiting the Anaconda site.

Development of the Media Cleanup Standard for Passerines

The Hoff (2002) report did not include a recommendation for allowable metals and arsenic concentrations in soil considered protective for passerine species. Metals concentrations in soil at the seven sites evaluated in the biomonitoring study were obtained from previously conducted investigations. The average lead concentration in soil of 655 mg/kg at Site K was the highest among the seven study sites. The subsequent ecological risk assessment reports (USEPA, 2005; Gradient, 2011) cite the average lead concentration in soil (rounded to 650 mg/kg) as a cleanup level but provide no narrative statement as to the basis for the cleanup level, or, in other words, the nature of the toxic endpoint associated with this lead concentration in soil.

The primary endpoints for lead exposure to passerines observed in this study were (1) interference in heme synthesis with no corresponding reduction in red blood cell production, and (2) accumulation of lead in kidney and liver tissues at subclinical levels for most individuals, but reaching toxic levels for a

[1] ALAD is a key enzyme in the synthesis of the heme protein, which is used to make red blood cells. Metals such as lead and copper can inhibit ALAD activity in birds and mammals (including humans), disrupting heme synthesis. This in turn has a deleterious effect on hematopoiesis (or the production of red blood cells) and can lead to anemia. ALAD depression in the blood is accompanied by elevated levels of porphyrins, macromolecules that are intermediates in heme synthesis (Eisler, 1988).

small proportion of exposed individuals. Other effect measures such as nesting, hatching, and fledging were considered within normal limits. Therefore, tissue accumulation of lead was not considered to be related to adverse reproductive effects.

Based on biomarkers of effect (depression of ALAD levels in blood; lead accumulation in tissues), the MCS of 650 mg/kg in soil might represent a lowest observed effect concentration (LOEC). However, there can be altered levels of biomarkers in exposed individuals in the absence of observable toxic effects (NAS, 2009). The altered biomarker levels reported in Hoff (2002) do not appear to predict serious adverse effects as defined in USEPA (1998): "…increased mortality, diminished growth, impaired reproduction, etc." Therefore, for purposes of assessing potential exposures to passerines from lead in soil, the MCS of 650 mg/kg represents a no observed effect concentration (NOEC) based on interference with red blood cell production (an early effect in the progression to anemia) and reproductive success, endpoints that are more relevant for a population or community. This NOEC is unbounded because a concentration at which adverse effects on growth, reproduction, or survival was not identified in the study.

Assessment of Lead in Soils at the Former ASARCO East Helena Facility

The primary uncertainty when extracting a risk-based soil concentration from the Hoff (2002) data is that approximately 650 mg/kg in soil was the highest concentration tested. While the study results show that 650 mg/kg lead in soil does not produce ecological risks (i.e., serious adverse effects) to passerines, it provides no information about ecological risks at higher concentrations. The potential for ecological risks to passerines from lead in soil at concentrations higher than 650 mg/kg was assessed with the following lines of evidence: (1) comparison with similar studies reported in the literature for mining sites in the Western United States; and (2) data in Hoff (2002) assessing the relationship between lead in soil and tissue levels in birds.

Similar Studies (Literature-based)

Risk-based concentrations of lead in soil for protection of songbirds have been developed for the CDA Basin Superfund site (Sample et al., 2011). The field study and laboratory methods used at the CDA Basin are comparable with those used in the Anaconda Smelter study (Hoff, 2002). The CDA Basin study estimated ecological preliminary remediation goals (PRGs) for songbirds using site-specific modeled relationships between soil concentrations and lead in liver and blood. Using these relationships along with tissue-based effect levels in the literature, a PRG in soil for songbirds based on subclinical lead levels in liver tissue was estimated to be 2,500 mg/kg. PRGs in soil also were estimated from literature-based toxicity reference values (TRVs) using lead concentrations measured in food items (ingesta) and wildlife foodchain models. PRGs in soil estimated for American robin, song sparrow, and Swainson's thrush ranged from 1,900 to 2,700 mg/kg using TRVs based on either a lowest observed adverse effect level (LOAEL) or an ED20 (Effective Dose – 20 percent[2]) (Sample et al., 2011).

Site-specific Soil-Tissue Relationships

Hoff (2002) reported a good relationship between soil lead and lead in liver tissue, and used these data to develop a model of lead accumulation in liver tissue as a function of soil concentration (see Figure 7-4, Hoff, 2002). The tissue concentrations were then compared with literature-based effect levels to assess the magnitude of ecological risk. Both Hoff (2002) and Sample et al. (2011) used literature-based liver tissue concentrations derived by Franson (Franson, 1996; Franson and Pain, 2011) as biomarkers of effect. The modeled relationship and these threshold levels were used to conduct an effects assessment

[2] The ED20 is the dose producing a specific adverse effect in 20 percent of a population, typically determined from studies with laboratory animals.

(similar to the risk estimation step in the ecological risk assessment process) on lead concentrations in soil at the East Helena site, as described below.

Effects Assessment. As discussed in the CMS Report, exposure concentrations of lead in soil (95 percent upper confidence limit [UCL] values) in CMS Parcels 2a and 15 were slightly higher than the MCS of 650 mg/kg. Calculating an ecological hazard quotient (HQ) using the MCS (i.e., HQ = exposure concentration/MCS) provides the following results (Table 1).

Table 1. Hazard Quotients

CMS Parcel	Parcel Size (Acres)	95 Percent Upper Confidence Limit Lead Concentration (mg/kg)	Hazard Quotient
2a	35	1,169	1.8
15	480	1,028	1.6

As described above, the MCS represents a NOEC for anemia, mortality, and reproductive endpoints. USEPA ecological risk management guidelines state that remediation should reduce unacceptable ecological risks where these risks are based on the potential for reduced diversity, increased mortality, diminished growth, impaired reproduction, etc. (USEPA, 1998). An HQ > 1 using a NOEC is not a trigger for remedial action at sites where special-status species are not present (such as at the Facility); in these cases, the exposure concentrations are compared with LOECs. LOECs represent the threshold at which there are concerns about adverse effects that may have impacts to populations or communities. A LOEC based on growth, survival, or reproduction could not be developed from the Anaconda Smelter study. Instead, further evaluation of Parcels 2a and 15 was performed in two ways:

- **Literature-based values:** The exposure concentrations (i.e., 95 percent UCL lead concentrations) were compared with LOAEL- and ED20-based PRGs derived by Sample et al. (2011; range = 1,900 to 2,700 mg/kg). The exposure concentrations in both parcels are below the lowest value in the PRG range (1,900 mg/kg).
- **Site-specific soil/tissue relationships:** Site-specific lead concentrations in liver tissue corresponding to the exposure concentrations were estimated using the soil-to-liver tissue relationship presented in Hoff (2002; see Figure 7-4). These modeled liver concentrations were then compared to liver tissue thresholds used in Sample et al. (2011) and shown in Table 2.

Table 2. Effects Levels in Birds Based on Lead Concentrations in Liver Tissue

Effect Level	Concentration in Liver (µg/g) w/w
Background	<2
Subclinical	2-6
Clinical	6-10
Severe Clinical	>10

Source: Sample et al., 2011.
Notes: µg/g = micrograms per gram; w/w = wet weight

Lead concentrations in liver tissue modeled for CMS Parcels 2a and 15 (3.14 and 2.8 µg/g, respectively) are within the range for subclinical effects (Table 3).

Table 3. Effects Assessment for Lead in Soil/Passerines at Former ASARCO East Helena Facility

CMS Parcel	Parcel Size (Acres)	95 Percent Upper Confidence Limit Lead Concentration (mg/kg)	HQ	Modeled lead concentration in liver (µg/g)	Effects Level - Sample et al., 2011
2a	35	1,169	1.8	3.14	subclinical
15	480	1,028	1.6	2.80	subclinical

Note:

Lead concentration in liver estimated from soil concentration using the following relationship presented in Hoff (2002), Figure 7-4: $y = 0.0024x + 0.3365$.

Subclinical effects are not considered serious adverse effects and therefore do not constitute unacceptable ecological risk.

Risk Characterization and Conclusion. The exposure concentrations for lead in soil in Parcels 2a and 15 were higher than the MCS of 650 mg/kg. The primary uncertainty with the MCS is that it is based on an unbounded NOEC for growth, reproduction, and survival. Given this uncertainty coupled with the low magnitude of exceedance (HQs < 2), risks to wildlife populations are likely not unacceptable in these parcels. This conclusion was supported by comparisons to risk-based thresholds developed for the CDA Basin (Sample et al., 2011), which were greater than the 95 percent UCL concentrations in Parcels 2a and 15. Additionally, liver tissue concentrations of lead estimated using the soil-to-tissue model developed for the Anaconda site (Hoff, 2002) were less than toxic levels (i.e., fell within the subclinical range) presented in both Sample et al. (2011) and Hoff (2002).

These results suggest that ecological risks, if present, are relatively small, do not represent potentially serious adverse effects, and are unlikely to have population- or community-level effects. Based on USEPA guidelines for ecological risk management (USEPA, 1998), these results would not represent unacceptable ecological risks. The small magnitude of ecological risk is a factor for consideration in determining the need for risk reduction (if any) and the type of action to be performed.

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Technical Memorandum: Calculation of a Lead Risk-Based Concentration (Soil Criteria for Cattle) at the Former ASARCO East Helena Facility

Calculation of a Lead Risk-Based Concentration (Soil Criteria for Cattle) at the Former ASARCO East Helena Facility

PREPARED FOR:	Cindy Brooks/GETG
COPY TO:	Lauri Gorton/GETG
PREPARED BY:	CH2M
DATE:	December 15, 2017

Risk-based concentrations (RBCs) are concentrations of a given analyte in abiotic media (e.g., soil) that correspond to a selected potential for adverse effects to the receptor such as a no observed adverse effect level (NOAEL). Modeling of RBCs is conducted within the ecological risk assessment guidance outlined by the U.S. Environmental Protection Agency (USEPA, 1997, 1998). Typically, ecological risk modeling is used to estimate the potential for risk to a given receptor at a site under defined conditions. This is often referred to as "forward" risk estimation. These modeling procedures can also be used in reverse (referred to as "back-calculation") to estimate concentrations in soil (i.e., soil RBCs) that correspond to a defined risk under the assumptions and limitations identified for the site.

An RBC for lead in soil at the Former ASARCO East Helena site (Facility) was calculated for cattle using published and Facility-specific information. Cattle may be exposed to lead from direct ingestion of soil while foraging on grass or from ingestion of grass that has taken up lead from the soil. The food chain uptake exposure model from Suter et al. (2000) was used to estimate potential daily exposure of cattle from diet and soil ingestion. The end product of the exposure estimate is an applied daily dose (milligram lead per kilogram of body weight per day [mg/kg/d]). The general equation for calculating the applied daily dose is shown below (Equation 1).

$$E_i = \left[\sum_{i-1}^{N} B_{ij} * P_i * FIR\right] + [Soil_i * P_s * FIR] * AUF \qquad \text{(Eq. 1)}$$

Where:

- E_j = total exposure dosage (mg/kg/d)
- B_{ij} = concentration of chemical (j) in biota type (i) (mg/kg)
- P_i = proportion of biota type (i) in diet (unitless)
- FIR = food ingestion rate normalized to body weight (kg/kg/d)
- $Soil_j$ = concentration of chemical (j) in soil (mg/kg)
- P_s = proportion of diet that is soil (unitless)
- AUF = area use factor (unitless)

To calculate a RBC for lead, species-specific life history factors, concentrations in diet, and toxicity reference values (TRVs) for adverse effects are needed.

Life history factors include body weight, food ingestion rate, and soil ingestion rate. Facility-specific values for these parameters are not typically available. Instead, values reported in published sources are used. In this case, body weight (272 kg), food ingestion rate (9,213 g/day, converted to 0.034 kg food per

kg body weight per day), and soil ingestion rate (9 percent or 0.09) for cattle as presented in Ford and Beyer (2014) were used. Although cattle are rarely expected to forage at the Facility, the AUF was assumed to be 1 (i.e., 100 percent use).

The concentrations in dietary items are typically modeled from soil concentrations measured at the Facility. However, lead concentrations in vegetation at the Facility are available and were presented in the Baseline Ecological Risk Assessment (BERA) (Gradient, 2011). Therefore, the geometric mean lead concentration in "Needle and Thread Grass (plant)," was used as the dietary concentration in the exposure estimate model. This was the highest value of the five types of plants tested at the Facility. The model is rewritten to use measured lead concentration in grass as follows (Equation 2):

$$E_i = [D_i * FIR] + [Soil_i * P_s * FIR] * AUF \qquad \text{(Eq. 2)}$$

Where:

D_j = concentration of chemical (j) in diet (mg/kg)

The lead TRV (3.2 mg/kg/day) used to calculate the lead RBC was developed in Ford and Beyer (2014) from the National Research Council's "Mineral Tolerances of Animals" (National Research Council, 2005). It represents "the dietary level that, when fed for a defined period of time, will not impair accepted indices of animal health or performance." It should be noted that this is a conservative value that is below the NOAEL (4.7 mg/kg/day) used by the USEPA to calculate mammalian ecological soil screening levels (Eco-SSLs) for lead (USEPA, 2005). Therefore, this TRV should not be considered a precedent for other sites, but rather a conservative benchmark for calculating soil criteria at the Facility.

In the forward risk estimation, the total exposure dose (diet exposure + soil exposure) is divided by the TRV to obtain a hazard quotient (HQ). As shown in Table 1, the exposure and risk estimation model is solved to find a soil concentration that results in a total dose that is equal to the NOAEL TRV. This is considered a back-calculation of the model. The soil concentration that produces a HQ value of one is the RBC.

Ford and Beyer (2014) performed a back-calculation of the exposure and risk model to develop soil criteria for livestock foraging at mining sites. They report a soil criteria for cattle of 1,127 mg/kg. CH2M performed the same calculation, but used a measured lead concentration in grass at the Facility. The resulting RBC or soil criteria is 955 mg/kg when based on the National Research Council's recommendation for a TRV, and 1,446 mg/kg when based on USEPA's TRV.

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Table 1. Risk-based Concentrations for Lead Exposure to Cattle

Technical Memorandum: Calculation of a Lead Risk-Based Concentration (Soil Criteria for Cattle) at the Former ASARCO East Helena Facility

		Exposure Parameters[a]				Vegetation Uptake				Soil Uptake							
Analyte	**Receptor**	Body Weight (kg)	Food Ingestion Rate (kg/kg/d)	Area Use Factor	RBC Soil Concentration (mg/kg)	Diet Proportion	Measured Vegetation Concentration (mg/kg)[b]	Vegetation Dose (mg/kg/day)		Soil Ingestion Rate[a]	Incidental Soil Dose (mg/kg/d)		**Total Dose (mg/kg//d)**	**NOAEL TRV (mg/kg/d)[c]**	**NOAEL-Based HQ (mg/kg/d)**		**NOAEL-Based RBC (mg/kg)[d]**
Lead	Cattle	272	0.034	1	955.1	1	8.16	0.28		0.09	2.92		3.20	3.2	1.00		955
Lead	Cattle	272	0.034	1	1446.0	1	8.16	0.28		0.09	4.42		4.70	4.7	1.00		1446

Notes:

[a] Exposure Parameters (body weight, food intake rate, and soil dietary proportion) for cattle are from "Soil Criteria to Protect Terrestrial Wildlife and Open-Range Livestock from Metal Toxicity at Mining Sites" (Ford and Beyer, 2014).

[b] Geometric mean concentration for "Needle and Thread Grass (plant)," n = 12; highest value of the 5 types of plants tested in the project area (Table 2.2 in Gradient [2011]).

[c] TRV of 3.2 mg/kg-day for lead was developed by Ford and Beyer (2014) from the National Research Council's "Mineral Tolerances of Animals" (NRC, 2005); represents "the dietary level that, when fed for a defined period of time, will not impair accepted indices of animal health or performance." TRV of 4.7 mg/kg-day for lead is a NOAEL developed by USEPA (USEPA, 2005).

[d] The NOAEL-Based RBC is derived by a back-calculation of the exposure and risk estimate; in this calcuclation, the exposure equation is solved to find the soil concentration that results in a total dose that is equal to the NOAEL TRV (i.e., the HQ = 1).

HQ = hazard quotient, where HQ= total dose / NOAEL TRV

kg = kilogram

mg/kg = milligram per kilogram

mg/kg/day = milligram per kilogram body weight per day

NOAEL = no observed adverse effect level

RBC = risk-based concentration; represents the soil concentration at which the total dose (i.e., the exposure estimate) equals the TRV

USEPA Memorandum (2017): Risks from Ingestion of Cattle Grazing on the East Field Parcel – East Helena

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 8
1595 Wynkoop Street
DENVER, CO 80202-1129
Phone 800-227-8917
http://www.epa.gov/region08

April 20, 2017

MEMORANDUM

SUBJECT: Risks from Ingestion of Cattle Grazing on the East Field Parcel – East Helena

FROM: Susan Griffin, PhD, DABT
Senior Toxicologist

TO: Betsy Burns
Remedial Project Manager

This memorandum is in response to your question regarding the risks posed to people who ingest beef from cattle which graze on the East Field Parcel in East Helena Montana. No tissue concentrations of lead or vegetation concentrations of lead were collected from the East Field Parcel. Only soil concentrations of lead were provided as shown in Table 1 below.

Table 1 – Soil Lead concentrations for the East Field Parcel

Soil Sample Location	Soil Sample ID	Sample Depth	Lead Result (mg/kg)
B01	EFRS-B01W-0002	0-2 feet	607
B03	EFRS-B03W-0002	0-2 feet	536
B04	EFRS-B04W-0002	0-2 feet	430
B06	EFRS-B06W-0002	0-2 feet	735
B07	EFRS-B07W-0002	0-2 feet	972
B07	EFRS-B07W-0002R	0-2 feet	1100
B08	EFRS-B08W-0002	0-2 feet	430
B09	EFRS-B09W-0002	0-2 feet	1210
B10	EFRS-B10W-0002	0-2 feet	555
B11	EFRS-B11W-0002	0-2 feet	368

To answer your question, I modeled the uptake of lead in soil into forage vegetation to obtain the concentration of lead in vegetation. I then modeled the uptake of lead in vegetation to cattle to obtain the concentration of lead in cattle tissue. This concentration was then input to EPA's Integrated Exposure Uptake Biokinetic (IEUBK) Model and Adult Lead Model to estimate the risk posed to

children and adults from the ingestion of the cattle tissue. A number of assumptions are utilized at each step of these modeling processes resulting in a high degree of both model and input parameter uncertainty. Comparisons between the model estimates and actual measured data at other sites suggest these types of models are overly conservative and tend to overestimate exposure. However, the best way to resolve this uncertainty is to collect and analyze actual data on the concentration of lead in both the forage vegetation and the cattle tissue. The individual modeling steps are shown below:

Soil Lead Exposure Point Concentration Term

Soil samples were collected from the East Field Parcel and analyzed for lead. The results are shown in Table 1. ProUCL 5.1 was used to derive the 95% upper confidence limit on the mean for an exposure point concentration term of 868 ppm. The data was normally distributed and the student T test was used to derive the term.

Uptake of Lead from Soil to Vegetation

The equation used to estimate uptake of lead from soil into plants was taken from EPA's Guidance for Developing Ecological Soil Screening Levels (USEPA 2007). Specifically,

$\text{Ln}(C_p) = 0.561 * \ln(C_s) - 1.328$

Where:
C_p = Concentration in plant tissue (mg/kg dry weight)
C_s = concentration in soil (mg/kg)

Table 2 – Uptake of Lead from Soil into Plants

C (mg/kg)	C plants (mg/kg dry weight)	C plants (mg/kg wet weight)
868	11.8	3.4

Uptake of Lead from Vegetation into Cattle Tissue

Uptake of lead from vegetation into cattle tissue was estimated using the approach described by Baes et al (1984). This approach was originally derived to estimate the concentration of radioactive elements in the muscle tissue of cows provided with contaminated feed. The basic equation is as follows:

$C\ (\text{tissue}) = \text{Daily Intake} * F_f$

C (tissue) = concentration of lead in muscle tissue (mg/kg wet weight)
Daily Intake = average daily ingestion rate of lead in the diet (mg/kg)
F_f = fraction of ingested dose that remains in muscle tissue (mg/kg per mg/day)

Daily Intake was calculated as follows:

Daily intake (mg/day) = C (veg) * IR (veg) * BW

Where:
C (veg) = concentration in vegetation ingested as food (mg/kg wet weight)
IR (veg) = dietary intake rate of vegetation (kg wet weight/kg body weight per day)
BW = body weight (kg)

Table 3 – Uptake of Lead from Plants into Cattle Tissue

C vegetation (mg/kg wet weight)	IR vegetation (kg/kg body weight)	BW (kg)	F_F (day/kg)	C tissue (mg/kg)
3.4	0.063[1]	544[2]	3.0E-04[3]	7.8 E-02

[1]Ingestion rate – Assumes a cow ingests 2.5% of its body weight on a dry weight basis
[2]Body weight – Assumes a mature beef cow weighs 1200 pounds
http://www.americancattlemen.com/articles/beef-cows-how-big-too-big
[3]Vegetation to beef uptake factor (Baes et al 1984)

Modeling Risks to Children and Adults from Ingestion of Beef

EPA's IEUBK model was used to estimate risks from ingestion of beef for children less than 7 years of age. The two primary non-default inputs to the IEUBK model were the concentration of lead in cattle tissue and the percentage of that cattle tissue ingested compared to all meats (beef, chicken, pork, wild game, etc.). EPA's Exposure Factors Handbook (USEPA 2011) suggested this would be approximately 20%. EPA's Adult Lead Model was used to estimate risks from ingestion of beef for adults. It was assumed that 100% of beef ingestion would come from the cattle grazing on the East Parcel Field. The primary non-default inputs to the Adult lead model were the concentration of lead in cattle tissue, the per capita ingestion rate of beef in the U.S. (USEPA 2011) and the bioavailability of lead from food.

Table 4 – Non-default Inputs to Lead Models

	IEUBK Model Inputs	Adult Lead Model Inputs
C (tissue)	7.8 E-02 ug/g	7.8 E-02 ug/g
% of all meats	20%	
Ingestion rate		27 gm/day
Absorption Fraction		33%

Results

When the lead concentrations from cattle grazing on the East Field Parcel are input to the IEUBK model, it is predicted that the geometric mean blood lead level would be 1.9 ug/dL with no more than a 0.02% probability of exceeding a blood lead level of 10 ug/dl (2.1% probability of exceeding 5 ug/dL). It is useful to note that the IEUBK integrates exposure from soil, water, air, and diet in addition to the site-specific intake of cattle.

The adult lead model predicts a geometric mean blood lead level of 2.8 ug/dL with a 0% chance of exceeding a blood lead level of 10 ug/dL (0.4% chance of exceeding 5 ug/dL). EPA considers lead risks to be unacceptable if the probability of exceeding a blood lead level of 10 ug/dl is greater than 5%.

Based on these calculations the ingestion of beef from the cattle grazing on the East Field Parcel would not be expected to result in any adverse health effects from lead.

References

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