TRI-PARTY AGREEMENT

Change Notice Number TPA-CN-872	TPA CHANGE NOTICE FORM	Date: September 30, 2019
Document Number, Title, and Revision: *Remedial Investigation Work Plan to Evaluate the 100-OL-1 Operable Unit Pre-Hanford Orchard Lands,* DOE/RL-2012-64, Rev. 0		Date Document Last Issued: June 2, 2016

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Description of Change:
This change revises the risk assessment task described in Chapter 4 of the work plan (DOE/RL-2012-64, Rev. 0) and adds additional tasks to describe a Feasibility Study (required by interim milestone M-015-97, reference change control form M-15-19-01). See "Justification and Impacts of Change" for details.
Note: In June 2016, 100-OL-1 OU changed a joint regulatory lead (EPA and Ecology) to a single regulatory lead (Ecology) in Appendix C of the Tri-Party Agreement Action Plan.

Michael Cline (**DOE**) and Kim Welsch (**Lead Regulatory Agency**) agree that the proposed change modifies an approved work plan/document and will be processed in accordance with the Tri-Party Agreement Action Plan, Section 9.0, *Documentation and Records,* and not Chapter 12.0, *Changes to the Agreement.*

- Modifications were made to Section 4.0 as shown in Attachment 1 (new text shown in red with underline; ~~deleted text shown in red with strikethrough~~). Includes revisions for Task RI-5 and additional tasks for the Feasibility Study. The entire Section 4.0 is provided.
- Attached white paper (Attachment 2) provides details on Task RI-5, which describes the development of site-specific Tier 2 risk-based soil concentration protective of ecological receptors for lead and arsenic.

Note: Include affected page number(s)

Justification and Impacts of Change:

- DOE and Ecology have agreed that the development of a site-specific Tier 2 risk-based soil concentration protective of ecological receptors for lead and arsenic is reasonable for evaluation of alternatives to consider in the Feasibility Study. The Tier 2 risk-based soil concentrations for lead and arsenic developed for the Central Plateau and considered in actions for other 100 Area waste sites does not represent the ecological risk associated with lead arsenate pesticide residues in 100-OL-1 Operable Unit. This action will integrate both site-specific and published exposure and effects information to quantify the presence, location, and magnitude of potential risks to ecological receptors. No supplemental work plan or DQOs are required to develop the site-specific Tier 2 ecological values for lead and arsenic because the effort does not involve field data collection.
- DOE and Ecology have agreed the tasks for conducting a Feasibility Study are consistent with DOE/RL-2012-64 (Rev. 0) and Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, (DOE/RL-2008-46, Rev. 0), as specified with the following additions.

Approvals

DOE Project Manager	Date 1/8/2020	[X] Approved [ ] Disapproved
NA EPA Project Manager	Date	[ ] Approved [ ] Disapproved
Ecology Project Manager	Date 1/8/20	[X] Approved [ ] Disapproved

4.0 Remedial Investigation and Feasibility Study Tasks

Table 4.1 includes the tasks identified for the 100-OL-1 OU RI. The feasibility study for the OU will be completed after the RI is approved by DOE, EPA, and Ecology. The RI tasks are discussed further below.

Table 4.1. RI Tasks

Task	Description of Task for Remedial Investigation
RI-1	Project Planning • RI Coordination • GIS Finalization of Decision Units • Cultural Resources Review • Ecological Compliance Review
RI-2	Field Characterization Activities
RI-3	Confirmatory Soil Analyses
RI-4	Data Evaluation
RI-5	Risk Assessment
RI-6	Remedial Investigation Report • Report Preparation • Review Cycle

Task RI-1: Project Planning. Several activities are included in project planning for successful implementation of the RI.

Subtask RI-1a – RI Coordination. Extensive fieldwork is planned for the RI. This task will 1) coordinate the activities needed for the RI; 2) update plans for field characterization, including the health and safety plan, SAP, and quality assurance project plan; and 3) coordinate with other work scope in the Hanford Site's River Corridor to facilitate characterization activities that are near other remediation actions (e.g., for DU-9 at 100-K Area). Coordination activities may include meetings with onsite contractors, additional site-specific training, and peer reviews. Communication on progress of field activities will occur weekly. Minor changes, including changes in sampling locations (e.g., less than 3 m [10ft]) due to obstructions, will be documented in field logs. More significant changes that affect the ability of the project to meet DQO or SAP (Appendix A) will require DOE-RL and regulator approval.

Subtask 1b – Finalization of Decision Units. Decision units identified in this work plan reflect updated information about the OU boundaries and finalized GIS documentation for the 100-OL-1 OU (Table 3.3). The updated OU boundaries with metadata, additional geo-referencing information, and new information about former orchards were provided to the Hanford GIS clearinghouse.

Subtask 1c – Cultural Resources Review (NHPA Section 106). Before the RI begins, a cultural resources review will be conducted to determine the potential for sampling locations to affect significant cultural resources and historic properties. This review will ensure that the field characterization activities are consistent with the *National Historic Preservation Act of 1966*. A similar review was performed for the 100-OL-1 OU pilot study (Bunn et al. 2014, MSA Service Catalog Request #KSR000000128277,

April 28, 2014). The cultural review will determine whether sample locations need to be moved to avoid cultural resources and when archaeological monitoring is required. The review will also describe any requirements for field sampling staff conducting work to ensure cultural resources are avoided during sampling activities.

Subtask 1d – Ecological Compliance Review. An ecological compliance review will be conducted, similar to the review performed for the 100-OL-1 OU pilot study (Bunn et al. 2014, MSA Service Catalog Request #KSR000000128277, April 28, 2014). This review will ensure that the field characterization activities do not conflict with laws, e.g., the *Endangered Species Act of 1973*, *Bald and Golden Eagle Protection Act*, *Migratory Bird Treaty Act*, and Washington State regulations protecting threatened, endangered, and listed species. A biological resource specialist will conduct the ecological compliance review.

Task RI-2: Field Characterization Activities. Field characterization activities will begin after the ecological and cultural review process is complete. Field activities for the characterization efforts will be completed in accordance with the SAP (Appendix A). Subcontracts for field activities may be required. Field characterization activities will be performed in accordance with the *Hanford Analytical Services Quality Assurance Requirements Documents* (DOE-RL 2014b) and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014). The step-out sampling, as discussed in Section 3.1.5, will be conducted after the field characterization within the OU has been completed. Data validation will be conducted by a third party who will perform an independent review of field data to ensure that the procedures, protocols, and requirements in the SAP were correctly followed. Data assessment will address any anomalies in the data and determine if corrective actions are needed. Validation and assessment of the data will be performed in accordance with the *DVZ-AFRI Quality Assurance Plan* (Meier 2014).

Task RI-3: Sample Analysis and Validation. Laboratory analyses of confirmatory soil samples (with ICP-MS) will be performed by a contract laboratory that has qualifications in accordance with the *Hanford Analytical Services Quality Assurance Requirements Documents* (DOE-RL 2014b) and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014). Data validation will be conducted by a third party who will perform an independent review of laboratory data to ensure that the procedures, protocols, and requirements in the SAP were correctly followed. Data assessment will address any anomalies in the data and determine if corrective actions are needed. Validation and assessment of the data will be performed in accordance with the *Hanford Analytical Services Quality Assurance Requirements Documents* (DOE-RL 2014b) and the *DVZ-AFRI Quality Assurance Plan* (Meier 2014).

Task RI-4: Data Evaluation. Data from field characterization will be evaluated to determine the magnitude and extent of lead and arsenic in the 100-OL-1 OU. Data evaluation will be consistent with DQOs and include comparison of field characterization results to screening levels for arsenic and lead concentrations in soil from each decision unit. The characterization results within the decision units will be presented visually (as in Bunn et al. 2014) and with summary statistics. The summary statistics for lead and arsenic in each decision unit include average, standard deviation, RSD, 95% upper confidence limit, maximum concentration, and number of detected values. Prior to computing summary statistics, the lead and arsenic detection limits for the XRF instrument will be established using the method detection limit calculations (40 CFR 136, Appendix B). Lead and arsenic concentrations measured by XRF and detected below the XRF's method detection limit will be treated as non-detects. For decision unit datasets with up to 50% non-detects (i.e., recorded by the XRF as "<LOD"), the Kaplan-Meier method will be used to compute summary statistics (e.g., mean, standard deviation, and upper confidence

limit). For decision unit datasets with the percentage of "<LOD" between 50% and 80%, alternative methods for computing summary statistics, besides Kaplan Meier, will be considered (e.g., robust regression on order statistics). For decision unit datasets with greater than 80% "<LOD," only descriptive statistics will be reported (e.g., percent detected and maximum concentration detected). Statistical packages, e.g., EPA's ProUCL, will be used to help determine the best alternative method for computing the summary statistics based on the dataset. The characterization data will be evaluated to determine if the data is of the right type, quality, and quantity to support the RI.

Task RI-5: Risk Assessment. Field characterization information from each decision unit will be evaluated in comparison to selected risk-based soil thresholds and screening levels for human and ecological health. The risk assessment will evaluate human health based on the decision rule (250 mg/kg lead and 20 mg/kg arsenic). The ecological risk evaluation in the risk assessment will compare the concentrations of lead and arsenic to the Tier 2 risk-based soil thresholds in Table 2.4, also called the preliminary remediation goals for the ecological receptors at the Hanford Site (CHPRC 2013). Additionally, a weight-of-evidence approach will be employed to evaluate the risks presented by lead and arsenic and be consistent in the development of a site-specific Tier 2 risk based soil threshold (EPA/540/R-97/006, DOE-STD-1153-2002, WAC 173-340-7493). No further collection of field data is proposed with this approach. This approach will integrate both site-specific and published exposure and effects information to quantify the presence, location, and magnitude of potential risks to ecological receptors. The approach outlined is to be performed in an iterative manner, and rely on existing and published data. ~~DOE may propose additional risk assessment work, which would require a supplemental work plan to establish DQOs for additional collection of site specific information.~~

Task RI-6: Remedial Investigation Report. This work element will consist of managing, compiling, and evaluating all of the data generated during the RI activities. The final report will cover activities ranging from field characterization of the orchards to evaluation of decision rules for determining further action in the decision units within the OU. A section will discuss the cleanup verification packages/remaining sites verification packages of the waste sites that are collocated within the OU. The section will include lead and arsenic results from closeout samples from WIDS sites within the boundaries of the OU. A section will summarize other 100 Area investigations (e.g., Remedial Investigation/Feasibility Studies, Columbia River Component Risk Assessment) concerning monitoring of lead and arsenic in other media (e.g., groundwater, porewater, surface water). Findings presented in this report will form the basis for future actions in the 100-OL-1 OU.

Task FS-1: Remedial Alternatives Development and Screening. The primary objective for the development and screening of remedial alternatives is to develop an appropriate range of remedial options that will be analyzed more fully in Task FS-2. Appropriate remedial options may include the complete elimination of hazardous substances, the reduction of concentrations of hazardous substances to acceptable health-based levels, and the prevention of exposure to hazardous substances via engineering or institutional controls. Typical alternatives for addressing lead arsenate residues in soil at former orchard sites will include institutional controls, excavation, vegetation stabilization, and soil mixing (e.g., as described in Ecology 2012a).

Remedial alternatives are developed by assembling combinations of technologies for affected media into alternatives that address the contamination for each area. This process consists of the following six general steps (EPA/540/G-89/004);

1. Develop Remedial Action Objectives (RAOs) for lead and arsenic in soil, exposure pathways, and Preliminary Remediation Goals (PRGs) that permit a range of treatment and containment alternatives to be developed. The PRGs are developed based on chemical specific applicable or relevant and appropriate requirements, other available information, and area-specific risk related factors.

2. Develop general response actions for soil defining containment, treatment, excavation, or other actions. singly or in combination, which may be taken to satisfy the RAOs for the area.
3. Identify volumes or areas of media to which general response actions might be applied, taking into account the requirements for protectiveness as identified in the RAOs and the chemical and physical characterization of the area.
4. Identify and screen the technologies applicable to each general response action to eliminate those technologies that cannot be technically implemented at the area. The general response actions are further defined to specify remedial technology types (e.g., the general response action of treatment can be further defined to include chemical or biological technology types).
5. Identify and evaluate technology process options to select a representative process for each technology type retained for consideration. Although specific processes are selected for alternative development and evaluation, these processes are intended to represent the broader range of process options within a general technology type.
6. Assemble the selected representative technologies into alternatives representing a range of treatment and containment combinations, as appropriate.

The screening should be used to identify and distinguish any differences among the various alternatives and to evaluate each alternative for effectiveness, implementability, and cost. The result of this task is a refined list of remedial alternatives for a specific area that is judged as the best or most promising based on these evaluation factors and should be retained for more detailed analysis.

The remedial action alternatives developed through this process are screened and FS-level designs and costs are developed for tbc preferred alternative.

Task FS-2: Detailed Analysis of Remedial Alternatives. During the detailed analysis, the alternatives that passed screening are further refined and analyzed. A number of alternatives should be developed that provide a range of options and sufficient information to compare alternatives against one another. For source control options, the following type of alternatives should be developed to the extent practicable.

- A number of treatment alternatives, ranging from an alternative that would eliminate or minimize to the extent feasible the need for long-term management (including monitoring) at a site, to an alternative that would use treatment as a primary component of an alternative to address the principal threats at the site. Alternatives within this range typically will differ in the type and extent of treatment used and the management requirements of treatment residuals or untreated wastes.
- One or more alternatives that involve containment of waste, with little or no treatment, but protect human health and the environment by preventing potential exposure and/or reducing the mobility of contaminants.
- A no action alternative.

The selection of the preferred alternative is determined through the application of nine evaluation criteria identified in the detailed analysis of alternatives. These criteria are grouped by their importance. Each alternative must meet the following threshold criteria:

- Overall protection of human health and the environment
- Compliance with ARARs

The analysis of alternatives is based on the following primary balancing criteria:

- Long-term effectiveness and permanence
- Reductions in toxicity, mobility, and volume through treatment

- Short-term effectiveness
- Implementability
- Cost

Modifying criteria evaluated following comment on the proposed plan and addressed in the ROD are as follows:

- State acceptance
- Community acceptance

Task FS-3: Feasibility Study Report. The final FS report presents the RAOs; development, screening, and detailed evaluation of remedial alternatives; and selection of the preferred remedy.

Attachment 2

Approach for Evaluation of Ecological Risks from Lead and Arsenic for the 100-OL-1 Operable Unit

1. Introduction

The purpose of this whitepaper is to outline the proposed approach for additional focused evaluation of ecological risks from lead and arsenic in 100-OL-1 OU. This approach is a modification to the *Remedial Investigation Work Plan to Evaluate the 100-OL-1 Operable Unit Pre-Hanford Orchard* (DOE/RL-2012-64, Rev. 0), Task RI-5. The results of this work will be incorporated into the *Remedial Investigation for the 100-OL-1 Operable Unit Hanford Orchard Lands* (DOE/RL-2016-54, Rev. 0). The proposed approach is consistent with WAC 173-340-7493 (Site-specific Terrestrial Ecological Evaluation) and USEPA Ecological Risk Assessment (ERA) guidance (USEPA 1997). The general approach is to employ weight-of-evidence to evaluate the risks presented by lead and arsenic, separately and in combination, in 100-OL-1 OU. This approach will rely exclusively on currently existing data; no further collection of field data is proposed. The proposed approach integrates both site-specific and published exposure and effects information to quantify the presence, location, and magnitude of potential risks to ecological receptors. This whitepaper is organized into six sections:

Section	Description
1	Introduction
2	Problem Formulation
3	Exposure Assessment
4	Effects Assessment
5	Risk Characterization
6	References

Historical use of lead arsenate as a pesticide in orchards at the Hanford Site has resulted in the accumulation of legacy lead and arsenic contamination in surface soils within 100-OL-1 OU. Initial evaluations indicate that the concentration of lead and arsenic may present a risk to certain terrestrial ecological receptors.
Based on an initial screening of the Exposure Point Concentration (EPC; or 95% Upper Confidence Limit [UCL]) for the 133 Decision Units (DUs) within 100-OL-1 OU, there are 29 DUs with an EPC that exceeds 156 mg/kg lead, the risk-based Tier 2 screening level for ecological risk (CHPRC 2014a). The risk-based Tier 2 screening level for lead is derived from a lowest observed adverse effect level (LOAEL) for Killdeer, an insectivorous bird. No DU has an EPC that exceeds 127 mg/kg arsenic, the risk-based Tier 2 screening level for ecological risk (CHPRC 2014a). However, there is some concern that the presence of lead and arsenic together may interact to create an additional ecological risk.

Toxicity reference values (TRVs) and bioaccumulation models from which the risk-based Tier 2 screening levels were developed, are not based on lead or arsenic derived from lead arsenate. As a consequence, the bioavailability, bioaccumulation, and toxicity data for lead and arsenic used in the Tier 2 screening levels may not adequately represent the forms present in 100-OL-1 OU (which originated from lead arsenate pesticide). An additional tier of ecological risk evaluation is being proposed that will employ bioavailability, bioaccumulation, and toxicity data as specific to lead arsenate as possible. This will include data collected from locations within the 100-OL-1 OU (i.e., Ecology 2011, Delistraty and Yokel 2014), literature-based studies performed using lead arsenate, and/or published field data collected from similar sites treated with lead arsenate.

2. Problem Formulation

The problem formulation is the first step of the ecological risk assessment process and includes a description of the site setting, identification of chemicals of potential ecological concern (COPECs), identification of the important aspects of the site to be protected (assessment endpoints), and the means by which the assessment endpoints will be

evaluated (measures of exposure and effects). The end product of the problem formulation is a conceptual site model that describes the contaminant sources and transport mechanisms, evaluates potential exposure pathways, and identifies the representative species used to assess potential ecological risk to those and other similar species.

2.1 Site Physical and Ecological Setting and History

Information on the physical and ecological setting and history of 100-OL-1 OU are presented in the 100-OL-1 OU RI.

2.2 Identification of Chemicals of Potential Ecological Concern

The COPECs that will be evaluated in this ERA are restricted to lead and arsenic.

2.3 Assessment Endpoints

Assessment endpoints are an expression of the important ecological values to be protected (Suter 1993; USEPA 1998; Suter et al. 2000), and are developed based on known information concerning the contaminants present, the study area, the ecological conceptual site model, etc. There are three components to each assessment endpoint: an *entity* (e.g., insectivorous birds), an *attribute* of that entity (e.g., individual survival), and a *measure* (e.g., a measurable value, such as an effect level). Measures are described following the general description of assessment endpoints (USEPA 1998; Suter et al. 2000).

Receptors (i.e., entities) selected for 100-OL-1 OU ERA are those considered in the Tiers 1 and 2 PRGs for the Hanford Site (CHPRC 2014a and CHPRC 2014b). These include terrestrial plants, soil invertebrates, birds (California quail, western meadowlark, killdeer, red-tailed hawk) and mammals (Great Basin pocket mouse, deer mouse, grasshopper mouse, and badger)[1].

Ecology questioned the selection of the grasshopper mouse to represent a mammalian insectivore as opposed to the shrew as outlined in MTCA Table 749-4. Surveys of mammals of the Hanford Site indicate only two shrew species to be present: Merriam's shrew (*Sorex merriami*) and the vagrant shrew (*Sorex vagrans*) (TNC 1998, USDOE 2017). Merriam's shrew, a candidate for threatened or endangered status, is restricted to higher elevation sagebrush steppe habitats on Rattlesnake Mountain (TNC 1998, Gitzen et al. 2001, USDOE 2017). Vagrant shrews have been reported from only a few locations at the Hanford Site and are most likely restricted to riparian habitats (PNL 1974, USDOE 2017). In contrast, the grasshopper mouse (*Onychomys leucogaster)* is widespread at the Hanford Site, although overall abundance is low (PNL 1974, Rickard and Poole 1989, TNC 1998, Gitzen et al. 2001). The grasshopper mouse was selected as the representative mammalian insectivore due to its broader distribution at the Hanford Site as compared to both shrew species. Merriam's shrew is not a suitable receptor for the 100-OL-1 OU because all DUs are at lower elevations, and thus not suitable habitat for this species. Although the majority of 100-OL-1 OU DUs are not adjacent to the Columbia River and riparian habitat, some are. It is therefore possible that vagrant shrews may be present and potentially exposed in some DUs. Consequently, vagrant shrews will be included as an additional mammalian insectivore receptor for those DUs that are adjacent to the Columbia River and riparian habitat. The American robin (*Turdus migratorius*) will also be included as a representative ground-feeding avian omnivore, to address questions from Ecology and to ensure consistency with MTCA Table 749-4.

Ecological attributes selected for all receptors will consist of growth, reproduction, and survival.

The proposed assessment endpoints for 100-OL-1 OU, their entities and attributes are summarized below:

Ecological Guild	Entity	Attribute
Primary Producers	Terrestrial Plants	Growth, Reproduction, Survival
Primary Consumers	Terrestrial Invertebrates	Growth, Reproduction, Survival
Avian Herbivore	California Quail	Growth, Reproduction, Survival
Avian Insectivore	Killdeer	Growth, Reproduction, Survival
Avian Omnivore	Western Meadowlark American Robin	Growth, Reproduction, Survival
Avian Carnivore	Red-tailed Hawk	Growth, Reproduction, Survival
Mammalian Herbivore	Great Basin Pocket Mouse	Growth, Reproduction, Survival
Mammalian Insectivore	Grasshopper Mouse	Growth, Reproduction, Survival

[1] Note that the inclusion of these substitute receptor species are subject to consideration by Ecology as outlined in WAC 173-340-7493(7).

Mammalian Insectivore (riparian DUs only)	Vagrant Shrew	Growth, Reproduction, Survival
Mammalian Omnivore	Deer Mouse	Growth, Reproduction, Survival
Mammalian Carnivore	Badger	Growth, Reproduction, Survival

2.4 Measures of Exposure and Effects

Measures (formerly referred to as measurement endpoints) are measurable attributes used to evaluate the risk hypotheses and are predictive of effects on the assessment endpoints (USEPA 1998). Whereas measures of exposure are used to evaluate levels at which exposures may be occurring, measures of effect are used to evaluate the response of the assessment endpoints when exposed to the stressors. Proposed measures for this ERA are outlined below.

2.4.1 Measures of Exposure

Measures of exposure can be an exposure point concentration (EPC) of a chemical in an environmental medium or food item, a related dose estimate, or a tissue-based concentration. Exposure in the 100-OL-1 OU ERA will be evaluated in multiple ways depending upon the receptor and the stage of the assessment:

Receptor	Initial Estimate of Exposure	Refined Estimate of Exposure
Terrestrial Plants and Invertebrates	Evaluation on a sample point by sample point basis by DU	Tabulate frequency of threshold exceedance over all samples within a DU
Birds and Mammals	Deterministic estimate of dietary exposure using 95%UCL as soil EPC	Probabilistic estimate of dietary exposure
Small Mammals	Deterministic estimate of tissue-based exposure using 95%UCL as soil EPC	Probabilistic estimate of tissue-based exposure

Terrestrial plants and invertebrates have no or limited mobility. They therefore experience exposure based upon the immediate location where they live. Exposure for these receptors will therefore initially be evaluated on a point by point basis for each DU. The frequency of threshold exceedance within a DU (aggregated adjacent DUs) will be used as a refined estimate of exposure for the terrestrial plant and invertebrate communities.

In contrast, birds and mammals are mobile and experience exposure averaged over the area they inhabit. The 95%UCL of the mean concentration in soil therefore represents a conservative, deterministic[2] EPC of their exposure. This soil EPC will be integrated into dietary models for all bird and mammal receptors (see section 3, below) and into soil-tissue models for small mammals (see section 3, below) to produce point estimates of exposure for each DU. Exposure for birds and mammals will also be evaluated probabilistically (i.e., based on whole distributions for model inputs as opposed to point-estimate inputs) to produce distributions of exposure estimated for each DU.

2.4.2 Measures of Effects

Measures of effects include media-specific ecological benchmarks and TRVs. Measures of effects for terrestrial plants and soil invertebrates will consist of results of site-specific bioassays and literature-derived thresholds for lead and arsenic. Literature-derived thresholds will include data based on studies of lead arsenate to the extent that such data are available. In the absence of these data, effect thresholds from studies using other forms of lead and arsenic will be used, with the recognition that these data impart greater uncertainty to the conclusions.

Measures of effects for birds and mammals will consist of literature-derived no observed and lowest observed adverse effects levels (NOAELs and LOAELs) and EDx[3] values derived from dose-response curve fitting. Literature-derived thresholds will include data based on studies of lead arsenate, to the extent that such data are available. In the absence of these data, effect thresholds from studies using other forms of lead and arsenic will be used, with the

[2] i.e., point-estimate
[3] EDx: effect dose where x=%effect.

recognition that these data impart greater uncertainty to the conclusions. Tissue-based effects for small mammals will also be evaluated based on literature-derived no and lowest effects concentrations (NOECs and LOECs).

2.5 Conceptual Site Model

The conceptual site model (CSM) is a written and visual presentation of predicted relationships among stressors, exposure pathways, and assessment endpoints. It includes a description of the complete exposure pathways and outlines the potential routes of exposure for each assessment endpoint. The source of lead and arsenic in the 100-OL-1 OU is historical application and spills of lead arsenate pesticide in the former orchards. Soil is the primary exposure medium. Terrestrial plants and invertebrates may be directly exposed to lead and arsenic in soil. Birds and mammals may be exposed to lead and arsenic in the soil through both incidental soil ingestion and through the food web. A CSM diagram for 100-OL-1 OU will be developed and included in the ERA report.

3. Exposure Assessment

The exposure assessment provides a description and quantification of the nature and magnitude of the interaction between COPECs in environmental media and ecological receptors. The exposure models and assumptions for each receptor at the Site are described as follows.

3.1 Direct Exposure

Terrestrial plants and invertebrates experience exposure primarily through the soil. This exposure is a consequence of living in soil that contain COPECs (i.e., receptors are directly exposed to COPECs). Although other exposure pathways (e.g., dietary exposure for invertebrates or foliar uptake) may contribute to total exposure for these receptors, exposure through the soil (or rather soil pore water) generally predominates (Allen 2002, USEPA 2007). Consequently, estimates of exposure for terrestrial plants and soil invertebrates may be represented by the concentration of COPECs in the soil (mg/kg). As previously indicated, exposure for terrestrial plants and soil invertebrates will be evaluated on a point by point basis within each DU.

3.2 Deterministic Dietary Exposure Modeling (Birds and Mammals)

Birds and mammals experience exposure through multiple pathways, including ingestion of abiotic media (soil) and biotic media (food), as well as inhalation and dermal contact.[4] To address this multiple pathway exposure requires modeling. The end product, or exposure estimate, for birds and mammals is a dosage (amount of chemical, in milligrams, per kilogram receptor body weight per day [mg/kg/day]) rather than a soil concentration, as is the case for plants and invertebrates. This is a function of both the multiple pathway approach and the typical methods used in toxicity testing for birds and mammals.

The general form of the dietary exposure model (Suter et al., 2000) is as follows:

$$E_t = \left[\left[\sum_{i=1}^{n} B_{ij} \times P_i \times FIR\right] + \left[Soil_j \times P_s \times FIR \times F_j\right]\right] xAUF$$

where

E_t = total dietary exposure (mg/kg per day)

AUF = area use factor

$Soil_j$ = concentration of chemical (j) in soil (mg/kg dry)

[4] Note that exposure to lead and arsenic through inhalation and dermal contact is assumed to be negligible or at least trivial in relation to dietary ingestion. Inhalation and dermal exposure for lead and arsenic for birds and mammals in 100-OL-1 OU will therefore not be considered further. Bench et al. (2001) report uptake of both manganese and cadmium via inhalation in California ground squirrels to be greater than estimated dietary uptake for cattle, suggesting elevated exposure through inhalation for fossorial mammals. In contrast, Moshkin et al. (2014) report that geometry of nasal passages in the fossorial mole vole (*Ellobius talpinus*) serves to limit accumulation of inhaled metal-containing dust, protecting brain and lung tissue from exposure to inhaled particles. Regardless, model-based screening-level risk analyses suggest that inhalation exposure and risks may be greater than ingestion exposure and risk for some metals (i.e., cadmium) in some scenarios (Archibold et al. 2007). The potential contribution from inhalation exposure total risk will be discussed as part of the uncertainty analysis in the risk characterization.

Ps = sediment ingestion rate as proportion of diet

FIR = species-specific food ingestion rate (kg food/kg body weight per day) wet weight

B_{ij} = concentration of chemical (j) in biota type (i) (mg/kg wet weight)

P_i = proportion of biota type (i) in diet

F_j = proportion of chemical (j) bioaccessible from soil

3.2.1 Model Parameterization

To apply the exposure model, appropriate model parameters must be defined. These model parameters are outlined as follows.

Exposure Point Concentrations. Because wildlife are mobile, traveling and experiencing exposure over the range of habitats they occupy, their exposure is best described by mean chemical concentrations in areas they inhabit (Suter et al. 2000). Therefore, 95UCLs provide a conservative measure of the mean. Deterministic EPCs will therefore consist of the 95UCL for each DU.

Life History Parameters. The spec ific life history parameters required to estimate exposure of each receptor to COPECs include body weight, food ingestion rates, dietary components and percentage of the overall diet represented by each major food type, and approximate amount of soil that may be incidentally ingested based on feeding habits. These parameters will be obtained from the literature and will be the same as those employed for the Tier 1 and Tier 2 PRGs (CHPRC 2014a and CHPRC 2014b). Data for life history parameters for the vagrant shrew will also be developed from the literature for inclusion in the ERA.

Many wildlife species are highly mobile, covering large areas in search of food, water, and shelter. The exposure that individuals experience depends on the amount of time they spend at a contaminated site. Site use depends on the size of the site relative to the receptor's home range. As a conservative assumption, wildlife receptors will be assumed to forage exclusively within each DU. Multiple adjacent DUs may be pooled for calculation of EPCs over broader spatial scales for receptors and DUs where estimated exposure exceeds selected TRVs. This analysis will be included in the uncertainty analysis to provide a more realistic, landscape scale estimate of exposure.

Bioaccumulation Models. Measurements of concentrations of lead and arsenic in wildlife foods (e.g., plants, terrestrial invertebrates, and small mammals) are a critical component for the estimation of oral exposure of birds and mammals. Soil-to-biota bioaccumulation models will be developed to estimate lead and arsenic concentrations in wildlife foods. These models will be developed based on co-located soil and biota samples collected from the 100-OL-1 OU or other published data from sites where lead arsenate has been applied[5]. Regression-based bioaccumulation models and bioaccumulation factors (BAF; biota/soil) will be developed in the same manner as that employed for the Tier 2 PRGs (CHPRC 2014a).

Bioaccessibility. Both the Tier 1 and Tier 2 PRGs assume that 100% of any analyte in incidentally ingested soil is bioavailable. Bioaccessibility is a measure of the fraction of a contaminant that may be extracted from the soil matrix in the gastrointestinal tract of exposed animals. This bioaccessible fraction represents the dose a bird or mammal may receive from incidentally ingested soil. Simulated gut digestion analysis methods have been developed and validated for both lead and arsenic (Ruby et al. 1996, Koch and Reimer 2012). Data generated by these methods may be used to represent the fraction of lead or arsenic in incidentally ingested soil that is bioavailable. At least five separate studies that report bioaccessibility data for lead and arsenic from lead arsenate treated soils have been identified (Gaw et al. 2008, Udovic and McBride 2012, Cai et al. 2016, Cai et al. 2017, Hail Environmental 2017). It should be noted however that Gaw et al. (2008) identified a number of barriers to using bioaccessibility data in risk assessments (e.g., lack of international consensus, limited information on long-term stability of bioaccessibility measurements, limitations of in vitro test methods, etc.).

Data from the studies listed above will be extracted and summarized for application in the uncertainty analysis of the ERA. Although default bioavailability of lead and arsenic in incidentally ingested soil will be assumed to be 100%, a

[5] Initial lead arsenate bioaccumulation data consists of 8 studies for 24 plant species; 2 studies with 2 arthropod species (one is Hanford-specific); at least 1 study and 2 mammal species.

sensitivity analysis will be performed, based on the lead arsenate-specific bioaccessibility data listed above, to quantify the influence that varying assumed bioavailability in ingested soil has on total estimated exposure. This sensitivity analysis will be included in the uncertainty section of the ERA and may serve as the basis for site-specific bioaccessibility analysis that could be performed as part of the Feasibility Study (FS).

3.3 Tissue-based Exposure Modeling

Lead concentrations in tissue are diagnostic of effects to birds and mammals (Franson and Pain 2011, Ma 2011). Soil-blood, kidney, and liver models have been developed and applied as part of the Coeur d'Alene ERA (USEPA 2001) and more recent work (Sample 2014). These models may be used to estimate tissue-lead concentrations for birds and mammals at the Hanford site, which can then be compared to literature-based effect thresholds for tissue. This analysis provides an independent line of evidence of lead exposure and risk for birds and mammals. Data from lead arsenate treated orchards for development of soil-kidney and liver models are available from at least 2 publications representing 2 species (Haschek et al. 1979, Elving et al. 1978). Preliminary, statistically significant models have been developed that may be used as an additional line of evidence for small mammals. Searches have been conducted for studies providing data for birds, but none have been located.
Tissue-based models for arsenic are not available.

3.4 Probabilistic Exposure Estimation

All initial estimates of exposure will be generated deterministically; that is, values for all parameters used in the models will be represented as single values or point estimates. These initial exposure estimates do not take into account the variation and uncertainty underlying the model parameters. As a consequence, point estimates of exposure may not accurately represent exposure, and depending upon the conservatism associated with the selected values used, may overestimate exposure. Additionally, calculating the models using point estimates produces a point estimate of exposure. This exposure estimate provides no information concerning the distribution of exposures or the likelihood that individual receptors residing at the 100-OL-1 OU will experience potentially hazardous exposures.

To incorporate the variation in exposure parameters and to improve resolution of exposure estimated to be experienced by bird and mammal receptors at the 100-OL-1 OU, dietary and tissue-based exposure estimates will be recalculated for selected species and analyzed probabilistically. Species and analytes retained for probabilistic analysis will be limited to those taxa–analyte combinations where deterministic exposure calculations suggest potential unacceptable risk (i.e., ED_{20} or LOEC exceedances).

Probabilistic exposure estimation will rely on the same food web and tissue-based models used for deterministic exposure estimates and will consist of assigning distributions to key parameters within the exposure models. The models will then be recalculated iteratively with values for the key parameters randomly selected from within the assigned distributions. The result will be a distribution of estimated exposure that expresses the variability and uncertainty associated with the key input parameters for which distributions were assigned. This exposure distribution will be compared to one or more TRVs to quantify the likelihood and magnitude of potential effects to exposed receptors.

Probabilistic analyses will be performed using Oracle Crystal Ball software (release 11.1.2.4.6). Model runs will be performed based on at least 10,000 iterations with samples from each input distribution selected using Latin hypercube sampling, which divides each input into a specified number of bins (in this case, 500) and then pulls a uniform number of samples from each bin. This sampling approach results in a more uniform and representative representation of the input distribution. Goodness-of-fit analyses will be performed on measured concentrations of lead and arsenic in soil using ProUCL (Version 5.0) or Crystal Ball software to identify appropriate distributions and associated parameters for probabilistic analyses. Distributions for additional model parameters necessary to apply the models will be developed and discussed with Ecology prior to performing probabilistic analyses.

4. Effects Assessment

The effects assessment summarizes available toxicity or other effects information that can be used to evaluate the exposures to COPECs and adverse effects in ecological receptors. Data that can be used include literature-derived or site-specific single-chemical toxicity data, site-specific ambient-media toxicity tests, and site-specific field surveys (Suter *et al.* 2000). Effects data that will be available for the 100-OL-1 OU consist of site-specific ambient-media toxicity tests and single-chemical toxicity data from literature sources.

4.1 Evaluation of Terrestrial Plants and Soil Invertebrates

Effects from lead and arsenic in 100-OL-1 OU soil will be evaluated based on both site-specific plant and soil invertebrate bioassay results from both Ecology (2011) and CHPRC (2014c), Additional analyses will be performed using literature-derived effects data for studies conducted using lead and arsenic from lead arsenate. Toxicity data based on other forms of lead or arsenic will only be used when appropriate data for lead arsenate are not available.

4.2 Birds and Mammals

Evaluation of dietary exposure estimates for birds and mammals requires effects thresholds or TRVs expressed as dietary doses. TRVs used in the Tier 1 and Tier 2 PRGs (CHPRC 2014a and CHPRC 2014b) consisted of NOAELs and LOAELs extracted from published literature. NOAELs and LOAELs, however, are poor representations of toxicity thresholds, as noted by Ecology in their comments on DOE/RL-2016-54, Draft A. Toxicity is best represented by EDx values (X% effective dose values; e.g., Beasley et al. 2015; http://onlinelibrary.wiley.com/doi/10.1002/etc.3086/pdf) derived by fitting dose-response relationships to the toxicity data. As an example, such analyses have been applied by USEPA as part of the Coeur d'Alene ERA (USEPA 2001) and were used in the recent recommended revision of the TRV for the avian lead Eco-SSL (Sample et al. 2019).

USEPA provides two tools that may be used to fit dose-response relationships to the toxicity data: the Benchmark Dose Software (BMDS; https://www.epa.gov/bmds/benchmark-dose-software-bmds-version-30) and the Toxicity Relationship Analysis Program (TRAP; https://archive.epa.gov/med/med_archive_03/web/html/trap.html). Dose-based toxicity data for lead and arsenic will be extracted from published studies and the USEPA tools will be employed to identify dose-response relationships. EDx values will then be extracted from these dose-response relationships for birds and mammals for growth, reproduction, or survival. Toxicity data will be evaluated for lead arsenate, lead acetate (or other lead salts), and sodium arsenate (or other arsenate salts) to provide insight into the relative toxicity of the lead and arsenate moieties. The lower of the ED_{20} (dose resulting in a 20% effect) values for growth, reproduction, or survival for birds and mammals will be selected as the TRV for each class for risk characterization.

Tissue-based effect threshold data are more limited than are dietary effect data and are not sufficient to support dose-response analyses. Tissue-based NOEC and LOEC values for lead and mammals and birds are reported in Ma (2011) and Franson and Pain (2011), respectively. Availability and suitability of tissue-based thresholds for arsenic will be investigated and reported to the extent that data are identified.

5. Risk Characterization.

In the risk characterization, exposure and effects data are integrated to draw conclusions concerning the presence, nature, and magnitude of effects that may exist and the associated uncertainties with the analysis. Risk characterization consists of two primary components: risk estimation and risk description (USEPA 1997). Risk is defined as the likelihood of adverse effects. The risk estimation integrates exposure and effects data to define a final estimate of potential adverse effects for each line of evidence. The risk description integrates each line of evidence in a weight of evidence (WoE) process to draw final conclusions relative to potential adverse effects.

5.1 Deterministic Risk Estimation

Risk estimation for deterministic data will be presented as the ratio of exposure concentrations or doses to TRVs, resulting in hazard quotients (HQs), and are described by the following equation:

$$HQ = C/TRV_m \text{ or } ED/TRV_d$$

where:

HQ	=	Ecological hazard quotient (unitless)
C	=	media concentration (mg/kg soil or tissue)
ED	=	Estimated chemical intake (dose) by wildlife receptor (mg/kg/day)
TRV_m	=	Medium-based Toxicity Reference Value (mg/kg soil or tissue)
TRV_d	=	Dose-based Toxicity Reference Value (mg/kg/day)

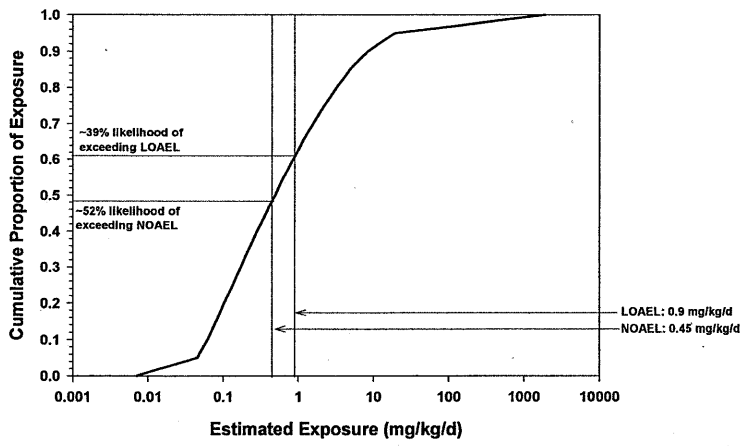
Interpretation of the significance of the HQ will depend upon the nature of the TRV:

- HQ<1 based on NOEC, NOAEL, or ED_{10} (dose associated with a 10% effect) TRVs indicate that adverse effects associated with exposure to a given analyte are unlikely (EPA 1997). Analytes, receptors, samples, or DUs for which HQs<1 for no-effect TRVs will be considered to present/be at no unacceptable risk.
- When estimated exposure results in an HQ≥1 based on a NOEC, NOAEL, or ED_{10} and an HQ<1 based on a LOEC, LOAEL, or ED_{20}, the conclusion is that risks are possible (exposure exceeds no effect levels) but is uncertain (exposure is less than levels at which significant effects are evident). If special-status species which require a higher level of protection are present, HQ≥1 based on a NOEC, NOAEL, or ED_{10} would be considered an indication of unacceptable risk.
- HQ≥1 based on a LOEC, LOAEL, or ED_{20} indicate adverse effects are possible, the significance of which will require additional analysis (point by point summation or probabilistic analysis).

Evaluation of risks to terrestrial plants and invertebrates will be evaluated on a point by point basis, with presence and severity of risk based on the frequency and magnitude of TRV exceedance. Risks to plants or invertebrates will be concluded if 20% or more samples from a DU (or other area of spatial aggregation of samples) exceed a LOEC or ED_{20} based threshold.

5.2 Probabilistic Risk Estimation

Risk estimation for probabilistic exposure estimation will be presented by overlaying TRVs representing different types and magnitudes of effects on the cumulative frequency distribution for estimated exposure. Unacceptable risks will be concluded if greater than 20% of the estimated exposure distribution exceeds the lowest LOEC, LOAEL, or ED_{20} TRV for growth, reproduction, or survival. For example, the figure below depicts risk because ~39% of the estimated exposure distribution exceeds the LOAEL.



Comparison of cumulative estimated exposure to literature derived NOAELs and LOAELs.

5.3 Mixture Toxicity

Lead and arsenic are both toxic inorganic analytes. Both are present in soils in the 100-OL-1 OU and therefore, ecological receptors in this OU will be exposed to both. Interactive or combined toxicity due to both lead and arsenic is possible. Some analyses, such as the site-specific bioassays (Ecology 2011) directly measure this possible interaction. The single-chemical exposure and effects analyses do not. Additional analyses are therefore required to evaluate combined toxicity of lead and arsenic.

Multiple reviews of approaches for evaluating toxicity of mixtures have been published (EC 2012, Kortenkamp et al. 2009, Vandenhove et al. 2012, Heys et al. 2016). The concentration addition (CA; also known as dose addition or DA) model is one of the simplest, albeit more conservative, mixture toxicity models available. The CA model is applicable if chemicals in a mixture have (or can be assumed to have) the same mode of action, differing only in their

relative potency (EC 2012, Kortenkamp et al. 2009, Vandenhove et al. 2012, Heys et al. 2016, ATSDR 2019)[6]. In CA, all chemicals in the mixture are assumed to behave as if they are simple dilutions of one another. The dose-response curves for each chemical in the mixture are parallel, and tolerance (or susceptibility) to the components is completely positively correlated (the organisms most susceptible to chemical A also will be most susceptible to chemical B). The response to the mixture can be predicted by summing the doses of the components after adjusting for the differences in potencies. Concentration addition is considered most appropriate for mixtures with components that affect the same endpoint by the same mode of action. The mixture dose/concentration (D_{mix}) is the sum of the scaled doses/concentrations ($\frac{Ci}{ECx_i}$) of the individual chemicals (i):

$$D_{mix} = \sum_{i=1}^{n} \frac{Ci}{ECx_i} \quad \text{(eq. 1)}$$

The toxicity of a mixture of similarly acting chemicals is equivalent to the effects of the sum of the potency- adjusted doses/concentrations of each chemical. Each fraction ($\frac{Ci}{ECx_i}$) represents the concentration of a mixture chemical (C_i) scaled for its relative toxicity (ECx_i) and is called the toxic unit (TU) of that chemical. CA is therefore also known as Toxic Unit Summation. The CA model relies on correctly grouping "similar" chemicals with comparable modes of action. However, there currently is no general agreement on the scientifically best approach and grouping of chemicals is most often done by expert judgement on a case-by-case basis (EC 2012).

The CA model has been recommended as the most suitable method for initial evaluation of contaminant mixtures by several authors. ATDSR (2019) suggests the CA model to be a reasonable *default* model likely to produce mixture toxicity estimates that range from appropriate to somewhat conservative, and would therefore be protective. Kortenkamp et al. (2009) also recommends the use of the CA model as a default first tier approach for the assessment of chemical mixtures due to its high predictive power over a considerable range of endpoints, organisms and chemicals, and its general conservatism. Kienzler et al. (2016) notes that CA models are the most frequently applied mixture model because they generally provide reliable estimates of combined effects, they can more easily be used with existing toxicity data and are considered to be slightly more conservative than independent action (IA) models. However, the results obtained by both CA and IA models are usually very similar and the difference between the predictions rarely exceed a factor of five. The CA model was also recommended by Bopp et al. (2018) for use as an initial, protective approach, that could be followed by more detailed analysis focused on chemical grouping based on common target organs and/or common modes of action.

The CA model is therefore the proposed method for integrating the combined effects of lead and arsenic. The recommended process for application of the CA model is as follows:

1. Identify the receptor group (i.e, birds or mammals) and effect endpoints (i.e., growth, reproduction, or survival) of interest for evaluation of lead and arsenic mixture effects
2. Identify lead and arsenic toxicity data for comparable test species within the selected receptor group and effects endpoint. Note that the greater the similarity between toxicity test species and effect endpoints, the lower the uncertainty will be for estimated mixture effects.
3. Develop dose-response relationships for the toxicity data for the selected receptor and effect endpoint for both lead and arsenic. Identify a common effect level (e.g., EC_{20}) for lead and arsenic.
4. Divide environmental concentrations, tissue concentrations, or dietary doses of lead and arsenic by the common effect level (i.e develop a toxic unit) and then sum the dividends.
5. If the sum of toxic units is less than one, mixture effects at the selected effect level are unlikely. If the sum of toxic units exceeds one, mixture effects are likely. The fractional contribution of lead and arsenic to combined toxicity can be determined by tabulating the proportion of total toxic units attributable to each analyte.

5.4 Weight of Evidence

The risk description (USEPA 1998) will employ a weight of evidence (WoE) approach to judge the relative quality of different lines of evidence and to integrate these different lines of evidence into an overall risk conclusion. The

[6] Note that the concentration addition model is quite similar to the derivation of hazard indices (HI) where HI=∑HQs. However, while calculation of an HI may be conducted with HQs derived from TRVs representing different modes of action and levels of effects, appropriate application of concentration addition requires that TRVs represent the same effect (i.e., egg production) and effect level (i.e., 20% reduction).

WoE approach will be consistent with EPAs *Weight of Evidence in Ecological Risk Assessment* (USEPA 2016) The application of WoE will be limited by the extent to which multiple lines of evidence are available for a given assessment endpoint.

5.5 Uncertainties

Uncertainties are inherent in all risk assessments. The nature and magnitude of the uncertainties depend on the amount and quality of data available, the degree of knowledge concerning site conditions, and the assumptions made to perform the assessment. Uncertainties associated with the ERA will be summarized and how they may affect conclusions will be described.

6. References:

Allen, HE. (2002) Bioavailability of metals in terrestrial ecosystems: importance of partitioning for bioavailability to invertebrates, microbes and plants. ISBN 1-880611-46-5. Pensacola, FL: SETAC Press, 158 pp.

Archbold, J.A. R.N. Hull, and M. Diamond. 2007 Potential Importance of Inhalation Exposures for Wildlife Using Screening-Level Ecological Risk Assessment. Human and Ecological Risk Assessment, 13:4, 870-883, DOI: 10.1080/10807030701456809

ATSDR (Agency for Toxic Substances and Disease Registry). 2019. Guidance Manual for Chemical Mixtures. Accessed July 15, 2019. https://www.atsdr.cdc.gov/interactionprofiles/ip-ga/ipga-c1-c5.pdf.

Beasley A, SE Belanger, JL Brill, and RR Otter. 2015. "Evaluation and comparison of the relationship between NOEC and EC10 or EC20 values in chronic Daphnia toxicity testing." Environmental Toxicology and Chemistry 34(10):2378-2384. Available at: http://onlinelibrary.wiley.com/doi/10.1002/etc.3086/pdf

Bench, G., Carlsen T., Grant, P., Wollett J., Martinelli, R., Lewis, J. and Divine, K.K. "Olfactory Bulb Uptake and Determination of Biotransfer Factors in the California Ground Squirrel (Spermophilus beecheyi) Exposed to Manganese and Cadmium in Environmental Habitats." *Environmental Science and Technology*, **35(2)**, (2001), 270-277.

Bopp, Stephanie K., et al. 2018. *Current EU Research Activities on Combined Exposure to Multiple Chemicals.* Environment International, 120: 544-562.

Cai M, M.B. McBride, K.Li. 2016. Bioaccessibility of Ba, Cu, Pb, and Zn in urban garden and orchard soils. Environ. Poll. 208:145-152.

Cai M., M.B. McBride, K.Li, and Z.Li. 2017. Bioaccessibility of As and Pb in orchard and urban soils amended with phosphate, Fe oxide and organic matter. Chemosphere. 173:153-159

Delistraty, D. and Yokel, J. (2014), Ecotoxicological study of arsenic and lead contaminated soils in former orchards at the Hanford site, USA. Environ. Toxicol, 29: 10-20. doi:10.1002/tox.20768

Ecology. 2011. Ecological Soil Screening Levels for Arsenic and Lead in the Tacoma Smelter Plume Footprint and Hanford Site Old Orchards. Publication No. 11-03-006, Toxics Studies Unit, Environmental Assessment Program, Washington State Department of Ecology, Olympia, Washington.

European Commission (EC). 2012. *Toxicity and Assessment of Chemical Mixtures*. Scientific Committee on Health and Environmental Risks (SCHER). Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Scientific Committee on Consumer Safety (SCCS). doi: 10.2772/21444

CHPRC (CH2M Hill Plateau Remediation Company). 2014a. Tier 2 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site. CHPRC-01311, Rev. 2, Richland, Washington.

CHPRC (CH2M Hill Plateau Remediation Company). 2014b. Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site. CHPRC-00784, Rev. 1, Richland, Washington.

CHPRC (CH2M Hill Plateau Remediation Company). 2014c. Tier 2 Terrestrial Plant and Invertebrate Preliminary Remediation Goals (PRGs) for Nonradionuclides for Use at the Hanford Site. ECF-HANFORD-11-0158, Rev. 1, Richland, Washington.

DOE/RL-2012-64. 2016. Remedial Investigation Work Plan to Evaluate the 100-OL-1 Operable Unit Pre-Hanford

Orchard Lands. Rev 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2016-54. 2017. Remedial Investigation for the 100-OL-1 Operable Unit Hanford Orchard Lands, Draft A. U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Elfving, D.C., et al. 1979. "Arsenic content of small mammals indigenous to old orchard soils," *Bull.Environ. Contam. Toxicol.* **21**, 62–4.

Franson, J.C., and D.J. Pain. 2011. "Lead in Birds." Pp. 563-593 in Beyer, W.N. and J. Meador (eds.) *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations*, 2nd. Ed. CRC Press, Boca Raton, FL. 751 pp.

Gaw, S., Kim, N., Northcott, G., Wilkins, A. & Robinson, G. (2008). Developing site-specific guidelines for orchard soils based on bioaccessibility – Can it be done? Chemistry in New Zealand, 72(2), 47-50.Gitzen, R.A., S.D. West, and B.E. Trim. 2001. Additional information on the distributions of small mammals at the Hanford Site, Washington. Northwest Science. 75: 350-362.

Hail Environmental. 2017. Waimea Orchards - Arsenic Bioavailability Assessment (Final). http://www.envirolink.govt.nz/assets/Envirolink/Reports/1774-TSDC133-Waimea-Orchards-Arsenic-Bioavailability-Assessment.pdf

Haschek WM, Lisk DJ, Stehn RA (1979) "Accumulations of lead in rodents from two old orchard sites in New York" in Animals *as Monitors of Environmental Pollutants,* Nat Acad Sci, Washington, DC, pp 192-199

Heys, Kelly A., Richard F. Shore, M. Gloria Pereira, Kevin C. Jones, and Francis L. Martin. 2016. *Risk Assessment of Environmental Mixture Effects*. The Royal Society of Chemistry (RSC) Advances, 6: 47844-47857.

Kienzler, Aude, Stephanie K. Bopp, Sander van der Linden, Elisabet Berggren, and Andrew Worth. 2016. *Regulatory Assessment of Chemical Mixtures: Requirements, Current Approaches and Future Perspectives*. Regulatory Toxicology and Pharmacy, 80: 321-334.

Koch, I, and K. Reimer. 2012. Bioaccessibility Extractions for Contaminant Risk Assessment. Pp. 487-507. In *Comprehensive Sampling and Sample Preparation*, Volume 3; Pawliszyn, J.; Le, X. C.; Li, X-F.; Lee, H. K.; Eds; Elsevier, Academic Press: Oxford, UK

Kortenkamp, Andreas, Thomas Backhaus, and Michael Fast. 2009. *State of the Art Report on Mixture Toxicity – Final Report.*

Ma, W.C. 2011. "Lead in Mammals." Pp. 595-608 in Beyer, W.N. and J. Meador (eds.) *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations*, 2nd. Ed. CRC Press, Boca Raton, FL. 751 pp.

Moshkin MP et al. 2014 Nasal aerodynamics protects brain and lung from inhaled dust in subterranean diggers, Ellobius talpinus. Proc. R. Soc. B 281: 20140919. http://dx.doi.org/10.1098/rspb.2014.0919

Pacific Northwest Laboratory (PNL). 1974. Mammals of the Hanford Reservation in Relation to Management of Radioactive Waste. BNWL- 1877. 53 pp.

Rickard, W.H. and L.D. Poole. 1989. Terrestrial Wildlife of the Hanford Site: Past and Future. Northwest Science. 63:183-193.

Ruby MV, Davis A, Schoof R, Eberle S, Sellstone C. 1996. Estimation of lead and arsenic bioavailability using a physiologically based extraction test. Environ Sci Technol 30: 422–430.

Sample BE. Dietary vs Tissue-based Risk Estimation for Lead in Small Mammals. Platform presentation at 2014 SETAC Meeting in Vancouver, BC. November 9-13, 2014.

Sample BE, Beyer WN, Wentsel R. *2019*. Revisiting the Avian Eco-SSL for Lead: Recommendations for Revision. *Int Environ Assess Manage.* 15:739-749

Suter, Glenn W., II, 1993, Ecological Risk Assessment, Lewis Publishers, Boca Raton, Florida.

Suter, G. W., II., R. A. Efroymson, B. E. Sample, and D. S. Jones. 2000. *Ecological Risk Assessment for Contaminated Sites*. Lewis Publishers, Boca Raton, Florida.

TNC (The Nature Conservancy). 1998. Biodiversity Inventory and Analysis of the Hanford Site. 1997 Annual Report. Prepared by the Nature Conservancy for USDOE. May 1998.

Udovic M, and M.B. McBride. 2012. Influence of compost addition on lead and arsenic bioavailability in reclaimed orchard soil assessed using Porcellio scaber bioaccumulation test. J. Haz. Materials. 205–206: 144-149.

USDOE. 2017. Hanford Site Biological Resources Management Plan. DOE/RL-96-32 Revision 2. https://www.hanford.gov/files.cfm/DOE-RL-96-32-01.pdf

USEPA. 1997. Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments. Interim Final. EPA/540/R-97/006.

USEPA. 1998. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F.

U.S. Environmental Protection Agency (USEPA). 2001. *Final Ecological Risk Assessment. Coeur d'Alene Basin Remedial Investigation/Feasibility Study*. Prepared by CH2M HILL and URS. Seattle (WA): USEPA Region 10.

USEPA (U.S. Environmental Protection Agency). 2007. Framework for Metals Risk Assessment. US EPA Office of the Science Advisor, Washington, DC, EPA 120/R-07/001,March 2007.USEPA (U.S. Environmental Protection Agency). 2016. Weight of Evidence in Ecological Assessment. US EPA Office of Research and Development, Washington, DC, EPA/100/R-16/001, 2016.

Vandenhove, Hildegarde, Nele Horemans, Rodolphe Gilbin, Steve Lofts, Almudena Real, Claire Bradshaw, Laureline Fevrier, Havard Thorring, Justin Brown, Deborah Oughton, Juan-Carlos Mora, Christelle Adam, Frederic Alonzo, Eline Saenen, Dave Spurgeon, and Brit Salbu. 2012. *Critical Review of Existing Approaches, Methods and Tools for Mixed Contaminant Exposure, Effect and Risk Assessment in Ecotoxicology and Evaluation of their Usefulness for Radioecology.* Strategy for Allied Radioecology (STAR).

WAC (Washington Administrative Code) 173-340-7493. Site-specific terrestrial ecological evaluation procedures. Available at: https://apps.leg.wa.gov/WAC/default.aspx?cite=173-340-7493