APPENDIX G

SOIL INVERTEBRATE AND PLANT TOXICITY BENCHMARKS

UPPER COLUMBIA RIVER

FINAL
Aquatic Baseline Ecological Risk Assessment
Appendix G
Soil Invertebrate and Plant Toxicity Benchmarks

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ACRONYMS AND ABBREVIATIONS

BERA	baseline ecological risk assessment
CEC	cation exchange capacity
COI	chemical of interest
COPC	chemical of potential concern
EC20	20 percent effect concentration
eCEC	effective cation exchange capacity
Eco-SSL	ecological soil screening level
EPA	U.S. Environmental Protection Agency
HQ	hazard quotient
NOEC	no-observed-effect concentration
PRG	preliminary remediation goal
RFDA	relict floodplain deposition area
RI/FS	Remedial Investigation and Feasibility Study
SSL	soil screening level
TAI	Teck American Incorporated
TOC	total organic carbon
UCR	Upper Columbia River
WSDA	windblown sediment deposition area

UNITS OF MEASURE

mg/kg-dw	milligram(s) per kilogram dry weight

1 INTRODUCTION

Teck American Incorporated (TAI) has conducted evaluations to derive terrestrial invertebrate and plant toxicity benchmarks for use in the baseline ecological risk assessment (BERA) for the relict floodplain deposition areas (RFDAs) and windblown sediment deposition areas (WSDAs) of the Upper Columbia River (UCR) site (hereafter the Site[1]). Hereafter, the BERA for the RFDAs, WSDAs, and Operable Units (OUs) 1 and 2 that cover the UCR is referred to as the Aquatic BERA. Terrestrial invertebrates and plants are evaluated in the Aquatic BERA because the data set includes terrestrial soils, which may contain metals transported from the river. Metals can be transported via either periodic flooding in RFDAs or wind deposition from periodically exposed sediment in certain areas within the river channel in WSDAs (see Sections 2.1 and 3.2.1.1 of Volume 4 for a description of the specific soil samples included from RFDAs and WSDAs). Soil toxicity benchmarks are used in hazard quotient (HQ) calculations to evaluate the potential for adverse effects on invertebrates and plants from direct contact exposure to chemicals of potential concern (COPCs) in soil. The strength, relevance, and reliability of HQs that use soil toxicity benchmarks as the measure of effect (i.e., the denominator) will be addressed in the weight of evidence evaluation in Sections 6 (plants) and 7 (invertebrates) of the Aquatic BERA.

Two methods were used to develop soil toxicity benchmarks. Both methods provide conservative estimates of adverse effect thresholds, wherein conservative means that the benchmark is less than the expected value of the corresponding adverse effect threshold. In other words, the estimation assumptions used to develop the terrestrial invertebrate and plant toxicity benchmarks are defined such that the probability of incorrectly concluding that an adverse effect threshold was not exceeded is low.

The objective of this appendix is to present the approach used to derive the soil toxicity benchmarks used in the Aquatic BERA. The terrestrial invertebrate and plant soil toxicity benchmarks described in this appendix build off work previously presented to the U.S. Environmental Protection Agency (EPA) in the *Draft Upper Columbia River Soil Evaluation for Plants and Invertebrates: Results from Steps 1 through 6 of the Proposed Approach* (TAI

[1] Per the June 2, 2006, Settlement Agreement for Implementation of Remedial Investigation and Feasibility Study at the Upper Columbia River Site (USEPA 2006), the Site consists of the areal extent of hazardous substances contamination within the United States in or adjacent to the UCR, including Franklin D. Roosevelt Lake, from the U.S.-Canada border to Grand Coulee Dam, and all suitable areas in proximity to such contamination necessary for implementation of the response actions (RI/FS) described therein.

2020a). Two types of soil toxicity benchmarks were presented in TAI (2020a): screening-level benchmarks (e.g., EPA ecological soil screening levels [Eco-SSLs]) and bioavailability-adjusted benchmarks calculated from a soil threshold calculator (similar to a predicted no-effect concentration). Additional screening-level benchmarks and bioavailability-adjusted benchmarks have been developed for use in the BERA that were not presented in TAI (2020a), because new COPCs[2] and chemicals of interest (COIs)[3] were added, or because TAI (2020a) did not evaluate some COPCs using bioavailability-adjusted benchmarks. While some COPCs and COIs are not "true" metals but rather metalloids, [4] COPCs and quantitatively evaluated COIs are collectively referred to as "metals" in the remainder of this appendix.

Section 2 of this appendix provides an overview of the approach used to develop the soil screening-level benchmarks and bioavailability-adjusted benchmarks. Section 3 of this appendix provides a summary of the benchmark values used in the Aquatic BERA. An uncertainty discussion for the benchmarks is provided in Section 4 of this appendix.

Details on the derivation of both benchmark types are presented in attachments to this appendix. Attachment G1 presents the EPA-approved Soil Screening Levels for Plants and Invertebrates for the Baseline Ecological Risk Assessment, which describes the development of soil screening levels (SSLs) for the eight metals lacking Eco-SSLs. Attachment G2 describes the derivation of bioavailability-adjusted benchmarks, which are not presented in Attachment G1. Attachment G2 also describes regionally relevant toxicity data from soil bioassays conducted for the Hanford site (located along the Columbia River, downstream of the UCR and north of Richland, Washington). These data will be important in the uncertainty evaluation for the soil screening benchmarks and the bioavailability-adjusted benchmarks.

[2] If the maximum detected concentration within an exposure area exceeded the Eco-SSL and more than one concentration exceeded the Eco-SSL, then the COI was considered a COPC for the receptor.

[3] As described in the COPC Refinement (TAI 2020b), certain COIs were retained for evaluation in the BERA based on uncertainties, including the following: COIs were not analyzed; COIs had no benchmark or screening-level toxicity reference value; a COI's detection limits exceeded the benchmark in more than one sample; or there was a single exceedance of the benchmark for a COI in a sample that had at least one other COI exceedance.

[4] Aluminum, barium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, silver, thallium, and vanadium are metals. Antimony, arsenic, and selenium are metalloids.

2 OVERVIEW OF PLANT AND INVERTEBRATE BENCHMARKS

This section provides an overview of how SSLs and bioavailability-adjusted benchmarks were developed for the Aquatic BERA. Details on their derivation are presented in Attachments G1 and G2 to this appendix. Table G-1 contains a list of metals for plants and invertebrates identified in the COPC Refinement (TAI 2020b)[5] that are evaluated in the Aquatic BERA, as well as the reports that include the benchmark derivations.

2.1 SOIL SCREENING LEVEL BENCHMARKS

When available, EPA's Eco-SSLs (USEPA 2016) were used as SSL benchmarks to evaluate the toxicity of metals to plants and invertebrates. SSLs were developed for metals when a plant and/or invertebrate Eco-SSL had not been developed. SSLs were developed for the Site by following the methods used by EPA to derive Eco-SSLs (USEPA 2003a). The approach used to develop SSLs is documented in Attachment G1, which was reviewed and approved by EPA. SSLs documented in Attachment G1 include those for the following:

- Antimony, chromium, molybdenum, and thallium for plants
- Arsenic, cobalt, molybdenum, silver, thallium, and vanadium for invertebrates.

In response to EPA's comments on TAI (2020a), TAI developed additional SSLs for two metal/receptor combinations not included in Attachment G1: barium/plants and chromium/invertebrates. The derivation of these SSLs followed the same procedures described in Attachment G1 and is presented in Attachment G2 of this appendix.

2.2 BIOAVAILABILITY-ADJUSTED BENCHMARKS

Bioavailability-adjusted benchmarks refine SSLs by accounting for the bioavailability of metals in soils. Bioavailability-adjusted toxicity effect levels for terrestrial plants and invertebrates were calculated for six metals while incorporating sample-specific soil properties that included organic matter content, percent clay, pH, and cation exchange

[5] The COPC Refinement (TAI 2019) included an addendum that was finalized in January 2020 (TAI 2020b). This citation (TAI 2020b) is used in the remainder of this appendix to cite the COPC Refinement document.

capacity (CEC). These data were collected as part of the 2014 Soil Study (TAI 2015). A soil threshold calculator (ARCHE 2020) was used to generate the sample-specific bioavailability-adjusted benchmarks, based on measured, sample-specific soil characteristics such as effective cation exchange capacity (eCEC) and pH. Bioavailability-adjusted benchmarks were developed for the following metal/receptor combinations for which relevant toxicity data are available:

- Cobalt, copper, lead, molybdenum, nickel, and zinc for plants
- Cobalt, copper, molybdenum, and zinc for invertebrates.

A detailed description of the derivation of the bioavailability-adjusted benchmarks is presented in Attachment G2 of this appendix.

3 RESULTS

Two benchmark types were developed for evaluating potential risk to terrestrial plants and invertebrates in the RFDAs and WSDAs: soil screening benchmarks (Eco-SSLs/SSLs) and bioavailability-adjusted benchmarks. Depending upon the availability of data, one or both benchmark types were developed for aluminum, antimony, arsenic, barium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, thallium, vanadium, and zinc, as appropriate for evaluating plants and/or invertebrates. These benchmarks are presented in Table G-2.

4 UNCERTAINTY

This section summarizes uncertainties associated with the selected soil benchmarks for plants and invertebrates.

4.1 ECO-SSLs/SSLs

The Eco-SSLs derived by EPA and the additional SSLs established following EPA's guidance for developing Eco-SSLs are intended to be conservative and applied during the screening stage of ecological risk assessments (USEPA 2003a). Key uncertainties in the terrestrial plant and invertebrate Eco-SSLs and SSLs are as described in the following sections.

4.1.1 Toxicity Tests Conducted in Soils with Physical and Chemical Properties that Favor Higher Bioavailability Conditions

EPA's Eco-SSL guidance notes that soil pH, CEC, clay content, and organic matter all influence metal bioavailability in soils, but only soil pH and organic matter are routinely reported (USEPA 2005a). Accordingly, soil toxicity test results compiled to support Eco-SSL development for the Site included bioavailability scores based on soil pH and organic matter. Eco-SSLs were weighted toward conditions that favored higher bioavailability. For example, for cationic metals (e.g., aluminum, antimony, barium, cobalt, copper, iron, lead, manganese, nickel, silver, thallium, and zinc), tests conducted using combinations of low pH and low organic matter conditions were given the highest possible bioavailability score of 2 (high/very high), and tests conducted in combinations of high pH and high organic matter conditions were given the lowest possible bioavailability score of 0 (very low/low).[6] Eco-SSLs are calculated based on tests with the highest bioavailability scores (i.e., those tests with a score of 2), if available for three or more tests. For cationic metals, tests with a bioavailability score of 2 have either a soil pH of 4.0 to 5.5 and an organic matter content ≤ 6 percent or a pH of 5.5 to 7.0 and an organic matter content < 2 percent. Eco-SSLs are increasingly conservative for metal cations (metals in aqueous solution) as the pH and organic matter content increase in Site soils relative to these ranges.

[6] Low pH and low organic matter favor increased bioavailability for cationic metals; the opposite is true for pH and anionic metals, such as chromium and vanadium.

The use of toxicity tests with the highest bioavailability scores is conservative and likely to overestimate the toxicity of contaminant concentrations in RFDA and WSDA soils. A summary of qualitative bioavailability scores using the criteria outlined by EPA (2005a) is provided for RFDA, WSDA, and Hanford soil samples in Table G-3. For the RFDA and WSDA soils, qualitative bioavailability scores are 0 or 1 (very low/low or medium) for 82 to 100 percent of samples for metal cations and 68 to 82 percent of samples for metal anions. Thus, for most soil samples from the RFDAs and WSDAs, bioavailability is likely to be less than that of the toxicity test conditions used to develop Eco-SSLs and SSLs. This difference in bioavailability is likely to overestimate the potential for adverse effects in HQs using Eco-SSL and SSL benchmarks.

4.1.2 Toxicity Tests Conducted in Unaged and/or Un-leached Soils

Soil toxicity tests with metals are typically conducted in soils freshly spiked with metal salts. The soil solution in freshly spiked soils, however, is rarely reflective of field-contaminated soils (Smolders et al. 2009). A freshly spiked metal salt increases the ionic strength of the soil and reduces the pH. In its Eco-SSL guidance, EPA recognized the importance of using aged soils for toxicity tests, but it noted that few studies to date had incorporated a step to create such soils (USEPA 2003a). Therefore, most of the toxicity tests that EPA used to develop metal Eco-SSLs were based on unaged and un-leached soils. As summarized by ARCHE (2020) and in Section 4.2 of this appendix, leaching and aging soils used in toxicity tests with metals can reduce toxicity by a factor of two to more than one order of magnitude; thus, Eco-SSLs and SSLs are conservative for field soils.

4.1.3 Relevance of Tested Plant and Invertebrate Species to Site Species

Eco-SSLs for plants are frequently based on species of agricultural significance, with common test species being ryegrass (*Lolium*), alfalfa (*Medicago sativa*), and barley (*Hordeum vulgare*). For invertebrates, commonly tested species are earthworms (*Lumbricina*) and springtails (*Collembola*). The relative sensitivities of commonly tested terrestrial plant and invertebrate species compared to Site species are unknown. However, for commonly tested metals—such as cadmium, copper, lead, and zinc—there is evidence that wild plants and crop plants are similarly sensitive:

- For cadmium, trees such as white pine (*Pinus strobus*), yellow birch (*Betula alleghaniensis*), and loblolly pine (*Pinus taeda*) are similar in sensitivity to several crop species. Data for these species, along with data for crop species, are incorporated into calculation of the EPA Eco-SSL (USEPA 2005d).

- For copper, the plant Eco-SSL is based on the geometric mean of soil toxicity thresholds for a variety of species including the more commonly tested alfalfa and ryegrass (*Lolium perenne* L.), but also including black bindweed (*Polygonum convolvulus*), a vine species, and the Cleopatra mandarin orange (*Citrus reshni*) (USEPA 2007a). Less sensitive plants species not included in calculation of the Eco-SSL were additional crop and grass species. Therefore, data from non-crop species contribute to the copper Eco-SSL, and there is no evidence that crop or non-crop species have unique sensitivities to copper.
- For lead, both loblolly pine and red maple (*Acer rubrum*) have sensitivities similar to that of clover (*Trifolium alexandrinum*) and ryegrass (*L. rigidum*), and toxicity threshold data for all four species were used to derive the lead Eco-SSL.
- For zinc, the Eco-SSL is based on toxicity threshold data for crop species, and all acceptable data for Eco-SSL development were for crop species. As such, at least based on the Eco-SSL data set, the relative sensitivities of crop and non-crop species to zinc cannot be summarized.

Thus, there is no evidence that non-crop species are more sensitive to metals than are crop species. For invertebrates, most available soil toxicity data are for earthworms and springtails, and the sensitivities of these organisms to metals relative to the sensitivities of other soil invertebrates are unknown. Overall, consistent with Eco-SSL guidance, the relative sensitivities of commonly tested terrestrial plant and invertebrate species are assumed to be adequately representative for conducting ecological risk assessments.

4.1.4 Toxicity Data Available for a Limited Number of Plant or Invertebrate Species

Some available toxicity data used to develop SSLs for metals met EPA's Eco-SSL guidance for test acceptability but did not meet EPA's guidance for the minimum number of toxicity tests required (i.e., data were available for only one or two tests; a minimum of three tests are required for Eco-SSL development). For example, plant SSLs for antimony and thallium and the invertebrate SSL for arsenic were each based on data from two tests, and the plant SSL for chromium and the invertebrate SSL for cobalt were each based on data from one test. It is unknown whether the uncertainties associated with such limited toxicity data may lead to the over- or underestimation of SSLs. However, the species tested were the same as, or similar to, test species used to derive Eco-SSLs that are assumed to be protective of terrestrial plant and invertebrate communities.

4.2 BIOAVAILABILITY-ADJUSTED BENCHMARKS

Bioavailability-adjusted benchmarks differ from Eco-SSLs/SSLs in the following ways: 1) benchmarks are adjusted to account for soil conditions that influence bioavailability to plants and invertebrates; 2) benchmarks are adjusted to account for soil aging, which also influences bioavailability; and 3) benchmarks are derived from the 5th percentile of a species sensitivity distribution of EC20s (20 percent effect concentrations). Key uncertainties associated with bioavailability-adjusted benchmarks are described in the following sections.

4.2.1 Bioavailability Equations Based on Physical and Chemical Soil Properties

The soil threshold calculator uses regression-based equations to predict the toxicity of a metal as a function of one or more soil properties that strongly influence metal bioavailability to plants and invertebrates; for each metal, separate regression models are used for plants and invertebrates. ARCHE (2020) reviewed regression-based bioavailability models developed for European, Australian, and Chinese soils that had been reported in peer-reviewed publications or in industry-sponsored studies conducted at university laboratories. ARCHE (2020) concluded that differences in the models were mainly due to differences in the methods used for soil analyses (e.g., measurement of CEC versus eCEC) and endpoints measured, and that the applicability of models would not be restricted to a specific region or soil type. Therefore, it is assumed that the regression-based bioavailability equations are applicable to a reasonably wide range of plant or invertebrate species, including tested species used to assess toxicity to species at the Site.

4.2.2 Bioavailability Adjustments for Soil Leaching and Aging

As noted in Section 4.1.2 of this appendix, spiking soil with metal salts for toxicity testing without a leaching or aging step can impact the ionic strength and pH of the soil, as well as overstate the bioavailability of metals relative to those in field soils (such as Site soils, since metal releases to RFDA and WSDA soils are historical). Since EPA’s Eco-SSL guidance was developed (USEPA 2003a), more studies have evaluated the influence of leaching and aging soil on metals toxicity to plants and invertebrates. The soil threshold calculator includes default leaching and aging factors that range between two and four for most metals. These factors typically range over one order of magnitude, with the default factors being conservative relative to the range of factors available. Accordingly, although the default leaching and aging factors lean toward conservatism, use of these factors decreases the overestimation bias present in Eco-SSLs and SSLs.

4.2.3 Applicability of Bioavailability-Based Benchmarks to Regional Conditions

The soil threshold calculator is based on models developed for European soils. ARCHE (2020), however, did conduct an evaluation of bioavailability corrections for North American soils and concluded that the soils used to develop the models covered the relevant range (10th to 90th percentile) of abiotic soil conditions in the U.S. and Canada. As such, soil conditions used to develop the European bioavailability models are not unique and can generally be applied to North America.

As a second point of assessment, bioavailability-adjusted soil benchmarks for plants and invertebrates were compared to the results of soil bioassays conducted using soils from the Hanford site. Bioassays were conducted with two regionally relevant test organisms: Sandberg bluegrass (*Poa secunda*) (28-day germination and growth) and springtail (28-day reproduction and survival) (CH2M Hill 2012). The percentage of soils with medium to very high bioavailability was, on average, greater for the Hanford soils than for the RFDA and WSDA soils using the Eco-SSL bioavailability scoring system (see Table G-3). Also, because the soils tested were field collected, they represented aged soils. No toxicity was observed in the bioassays, so toxicity thresholds for individual metals in the field-collected soils could only be defined as greater than no-observed-effect concentrations (NOECs). Using lead and zinc as example metals,[7] bioavailability-adjusted benchmarks for Hanford soils were almost always less than unbounded NOEC-based Hanford preliminary remediation goals (PRGs) for lead (plants) and zinc (plants, invertebrates), sometimes by less than an order of magnitude. This pattern indicates that the bioavailability-based benchmarks for Hanford soils provide a level of protection similar to or greater than that associated with the approved PRGs for Hanford soils. The UCR RFDA and WSDA soils have bioavailability conditions for lead (plants) and zinc (invertebrates) comparable to those of Hanford soils, and generally have greater bioavailability conditions for zinc (plants). Differences in bioavailability, when they occur, are accounted for in the bioavailability-based benchmarks. Therefore, conclusions on the protectiveness of bioavailability-based benchmarks for Hanford soils relative to that of unbounded

[7] Copper concentrations were relatively low in the Hanford soils. Lead is a UCR COPC for terrestrial plants and zinc is a UCR COPC for both terrestrial plants and invertebrates.

NOEC-based PRGs are assumed to also apply to UCR RFDA and WSDA soils. The details of this bioavailability comparison are provided in Attachment G2.

4.2.4 Relevance of Tested Plant and Invertebrate Species to Site Species

The tests used to develop bioavailability-adjusted benchmarks are frequently based on plant species of agricultural significance; for invertebrates, commonly tested species are earthworms and springtails. As noted, however, plant species used to develop the Eco-SSLs for metals are often both crop and non-crop species, indicating that neither crop nor non-crop plants are uniquely sensitive. As such, the toxicity data for plant species used to derive the bioavailability-based benchmarks are likely to be protective of Site species. Furthermore, the toxicity data sets used to develop the bioavailability-based benchmarks are recent and include studies that were not available when EPA developed the Eco-SSLs. This increases the likelihood of more sensitive species being tested and incorporated into the benchmarks.

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TABLES

Table G-1. Plant and Invertebrate Soil Toxicity Benchmark Sources

Metal	COPC/COI	Soil Benchmark Source: Screening Level (Eco-SSL/SSL)	Soil Benchmark Source: Bioavailability-Adjusted Benchmark (Threshold Calculator)
Plants			
Aluminum	COPC	USEPA (2003b)	NA
Antimony	COI	Attachment G1	NA
Arsenic	COPC	USEPA (2005b)	NA
Barium	COPC [a]	Attachment G2	NA
Chromium	COI	Attachment G1	NA
Cobalt	COPC	USEPA (2005e)	ARCHE (2020) [b]
Copper	COPC	USEPA (2007a)	ARCHE (2020) [b]
Iron	COPC	USEPA (2003c)	NA
Lead	COPC	USEPA (2005f)	ARCHE (2020) [b]
Manganese	COPC	USEPA (2007b)	NA
Molybdenum	COI	Attachment G1	ARCHE (2020) [b]
Nickel	COPC	USEPA (2007c)	ARCHE (2020) [b]
Selenium	COPC	USEPA (2007d)	NA
Thallium	COI	Attachment G1	NA
Zinc	COPC	USEPA (2007e)	ARCHE (2020) [b]
Invertebrates			
Aluminum	COPC	USEPA (2003b)	NA
Arsenic	COI	Attachment G1	NA
Barium	COPC	USEPA (2005c)	NA
Chromium	COI	Attachment G2	NA
Cobalt	COI	Attachment G1	ARCHE (2020) [b]
Copper	COPC	USEPA (2007a)	ARCHE (2020) [b]
Iron	COPC	USEPA (2003c)	NA
Manganese	COPC	USEPA (2007b)	NA
Molybdenum	COI	Attachment G1	ARCHE (2020) [b]
Silver	COI	Attachment G1	NA
Thallium	COI	Attachment G1	NA
Vanadium	COI	Attachment G1	NA
Zinc	COPC	USEPA (2007e)	ARCHE (2020) [b]

Notes:

[a] Barium was originally identified as a chemical of interest (COI) in the Chemical of Potential Concern (COPC) Refinement, but is now identified as a COPC at the request of EPA (see Attachment G2).

[b] Usage and calculations described in Attachment G2.

Eco-SSL - ecological soil screening level

NA - not applicable, benchmarks could not be developed for these metals

SSL - soil screening level

Table G-2. Plant and Invertebrate Soil Toxicity Benchmarks

		Soil Benchmark (mg/kg-dw)		
Metal	COPC/COI	Screening Level (Eco-SSL/SSL)	Screening Level (Eco-SSL/SSL) Bioavailability Conditions [a]	Bioavailability-Adjusted Benchmark (Threshold Calculator)
Plants				
Aluminum	COPC	pH < 5.5	NA	NA
Antimony	COI	1900 [b]	medium (1)	NA
Arsenic	COPC	18	medium (1), high or very high (2)	NA
Barium	COPC	1414 [b]	very low or low (0)	NA
Chromium	COI	190 [b]	high or very high (2)	NA
Cobalt	COPC	13	high or very high (2)	9.7–86
Copper	COPC	70	high or very high (2)	84–310
Iron	COPC	pH < 5.0	NA	NA
Lead	COPC	120	high or very high (2)	170–480
Manganese	COPC	220	medium (1), high or very high (2)	NA
Molybdenum	COI	26 [b]	high or very high (2)	0.31–180
Nickel	COPC	38	high or very high (2)	14–110
Selenium	COPC	0.52	high or very high (2)	NA
Thallium	COI	3.2 [b]	medium (1)	NA
Zinc	COPC	160	high or very high (2)	69–290
Invertebrates				
Aluminum	COPC	pH < 5.5	NA	NA
Arsenic	COI	153 [b]	medium (1), high or very high (2)	NA
Barium	COPC	330	high or very high (2)	NA
Chromium	COI	57	medium (1)	NA
Cobalt	COI	130 [b]	high or very high (2)	50–130
Copper	COPC	80	high or very high (2)	37–110
Iron	COPC	pH < 5.0	NA	NA
Manganese	COPC	450	high or very high (2)	NA
Molybdenum	COI	233 [b]	high or very high (2)	8.9–130
Silver	COI	58 [b]	high or very high (2)	NA
Thallium	COI	30 [b]	medium (1)	NA
Vanadium	COI	294 [b]	medium (1)	NA
Zinc	COPC	120	high or very high (2)	100–490

Notes:

[a] The reported bioavailability scores in this table are those for the toxicity data sets that were used to derive the ecological soil screening level (Eco-SSL) / soil screening level (SSL) benchmarks. Bioavailability scores were calculated by EPA for the Eco-SSLs, and in Attachments G1 and G2 for SSLs, as per Attachment A of USEPA (2003d) and Tables 2.4a, 2.4b, and 2.6 of USEPA (2005b), using the cation and anion lists presented in Table 2.1 of USEPA (2005b). The bioavailability scores are based on soil pH and organic matter content, and are as follows: 0 = very low or low, 1 = medium, 2 = high or very high.

[b] Eco-SSLs were not available for this chemical/receptor combination. SSLs were developed and used instead (Attachment G1, Attachment G2).

dw - dry weight

COI - chemical of interest

COPC - chemical of potential concern

NA - not applicable

Table G-3. Qualitative Bioavailability of Metals for Soil Samples Using Eco-SSL Classifications [a]

Number of Samples	Bioavailability	Score	Metal Cations [b]		Metal Anions [c]
			Plants	Invertebrates	Plants and Invertebrates
RFDAs					
25 [d]	very low	0	0%	0%	0%
	low	0	72%	44%	44%
	medium	1	28%	56%	24%
	high	2	0%	0%	28%
	very high	2	0%	0%	4%
WSDAs					
17	very low	0	0%	0%	18%
	low	0	35%	35%	35%
	medium	1	47%	47%	29%
	high	2	18%	18%	18%
	very high	2	0%	0%	0%
Hanford Soil Samples					
59 [e]	very low	0	14%	14%	1.7%
	low	0	24%	3.4%	10%
	medium	1	49%	70%	15%
	high	2	6.8%	6.8%	27%
	very high	2	6.8%	6.8%	46%

Notes:

[a] Qualitative bioavailability scores are calculated as per Attachment A of USEPA (2003d) and Tables 2.4a, 2.4b, and 2.6 of USEPA (2005b), using the cation and anion lists presented in Table 2.1 of USEPA (2005b). Bioavailability parameters used in determining scores are soil pH and organic matter. Because included soil samples only report total organic carbon (TOC), a conversion factor (1.72) is used to convert TOC to organic matter. For cases where the estimated organic matter is higher than the range of the bioavailability scoring rubric in Attachment A of USEPA (2003d), organic matter was capped at the high end of the rubric range; this results in a conservative bioavailability score. All soil samples used in the RFDA and WSDA BERA were included in this table, except where noted.

[b] Metal cations are aluminum, antimony, barium, beryllium, cadmium, cobalt, copper, iron, lead, manganese, nickel, silver, and zinc.

[c] Metal anions are arsenic, chromium, molybdenum, selenium, and vanadium.

[d] Sample XRF-26 from the 2019 Northport Waterfront RI does not have data for pH or organic carbon and is therefore omitted from this count.

[e] Three samples collected at Old Orchard by Ecology do not have data for pH and are therefore omitted from this count.

Eco-SSL - ecological soil screening level

RFDAs - relict floodplain deposition areas

WSDAs - windblown sediment deposition areas

ATTACHMENT G1

SOIL SCREENING LEVELS FOR PLANTS AND INVERTEBRATES FOR THE BASELINE ECOLOGICAL RISK ASSESSMENT

Orr Rob SPOK

From: Cerise, Kathy <Cerise.Kathryn@epa.gov>
Sent: Tuesday, February 11, 2020 3:02 PM
To: McCaig Kris SPOK
Cc: Gauthier, Marilyn/PDX; Roark, Shaun/DEN; Latier, Andrea
Subject: RE: Bi-weekly Eco RA Call - February 12, 2020

[External email]

Kris

EPA has reviewed TAIs revisions and responses to comments for Item 3 - (Soil Screening Levels for Plants and Invertebrates for the Baseline Ecological Risk Assessment). We agree that the Tech Memo can be finalized.

Thanks

Kathryn Cerise
UCR RPM

Kathryn Cerise
Region 10 Remedial Project Manager
1200 6th Ave,
Seattle, WA 98101
Mail Code: 12 D12 1
Phone: 206-553-2589

From: McCaig Kris SPOK <Kris.McCaig@teck.com>
Sent: Tuesday, February 11, 2020 9:56 AM
To: Cerise, Kathy <Cerise.Kathryn@epa.gov>
Cc: Mills Denise SPOK <Denise.Mills@teck.com>; Orr Rob SPOK <Rob.Orr@teck.com>; Kessel Cristy SPOK <Cristy.Kessel@teck.com>
Subject: Bi-weekly Eco RA Call - February 12, 2020

Hi Kathy,

Given TAI and EPA have calls scheduled for tomorrow and Thursday to discuss specific technical topics (i.e., BERA Weight of Evidence webinar Part 2 and Background Soil Assessment comments respectively), we would like to suggest cancelling the bi-weekly Eco RA call scheduled for 1PM Pacific tomorrow. Instead it would be helpful for TAI to receive an email from you with information you can share regarding when we may receive comments on the following:

1. December 12, 2020 Draft Phase 3 Sediment Study Change Request No. 6 for Porewater Extraction Methods to be Used During Bioassays
2. January 27, 2020 Revised Draft Technical Memo – Phase 3 Sediment Study Bioassay Sample Selection and Batching
3. January 29, 2020 Revised Draft Technical Memo – Soil Screening Levels for Plants and Invertebrates for the Baseline Ecological Risk Assessment (approval to finalize?)

4. February 5, 2020 Revised Draft Technical Memo – Backscatter Electron Microscopy Sample Selection and Procedures
5. February 7, 2020 Revised Draft Technical Memo – Additional TIE Pilot Study Testing

For your reference and sharing with your team, I am also attaching the updated Draft Deliverables Schedule. Please confirm you agree with cancelling the bi-weekly call and I will remove it from our calendars.

Thank you,

Kris

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MEMORANDUM

To: Teck American Incorporated

From: Windward Environmental LLC

Subject: Soil Screening Levels for Plants and Invertebrates for the Baseline Ecological Risk Assessment

Date: January 29, 2020

INTRODUCTION

As outlined in the *Proposed Approach for Evaluating the Potential for Metals Toxicity to Plants and Invertebrates in the Baseline Ecological Risk Assessment (BERA) for the Upper Columbia River Remedial Investigation and Feasibility Study* (Windward 2019a), the first step in the risk assessment for plants and invertebrates is a comparison of metals concentrations in Upper Columbia River (UCR) soils to the U.S. Environmental Protection Agency's (EPA's) ecological soil screening levels (Eco-SSLs) for plants and invertebrates (USEPA 2016). Among the metals analyzed in UCR soils, eight lack an Eco-SSL or soil screening level benchmark for plants, invertebrates, or both (Table 1)[1] and therefore could not be screened in the draft final Chemicals of Potential Concern (COPC) Refinement (Windward 2019b). For six of these metals (antimony, arsenic, chromium, cobalt, silver, and vanadium), Eco-SSL documents were prepared, but Eco-SSL values could not be derived for either plants, invertebrates, or both because of

[1] In addition to the eight metals discussed in herein, EPA (2016) states that Eco-SSLs are not available for aluminum "[b]ecause the measurement of total aluminum in soils is not considered suitable or reliable for the prediction of potential toxicity and bioaccumulation, an alternative procedure is recommended for screening aluminum in soils. The procedure is intended as a practical approach for determining if aluminum in site soils could pose a potential risk to ecological receptors. This alternative procedure replaces the derivation of numeric Eco-SSL values for aluminum. Potential ecological risks associated with aluminum are identified based on the measured soil pH. Aluminum is identified as a COPC only at sites where the soil pH is less than 5.5."

insufficient toxicity data. For two additional metals, molybdenum and thallium, Eco-SSL documents were never developed. The purpose of this document is to describe the development of soil screening levels for the eight metals lacking Eco-SSLs following EPA's Eco-SSL guidance.

Table 1. Metals needing soil screening levels

Metal	Soil Screening Level Needed?	
	Plants	Invertebrates
Antimony	yes	no[a]
Arsenic	no[b]	yes
Chromium	yes	no[a]
Cobalt	no[b]	yes
Molybdenum	yes	yes
Silver	no[a]	yes
Thallium	yes	yes
Vanadium	no[a]	yes

[a] A soil screening level is not needed because the metal is not a COPC for the receptor indicated.

[b] A soil screening level is not needed because there is an Eco-SSL value for the receptor indicated.

Eco-SSL – ecological soil screening level

METHODS

Compilation of toxicity data

The first step in developing the soil screening levels was to compile available and relevant toxicity data. For cobalt and molybdenum, the recently updated threshold calculator for metals in soil (V2.0) (ARCHE 2018) was relied on as the source of toxicity data. For antimony, arsenic, chromium, silver, and vanadium, which are not included in ARCHE's threshold calculator, toxicity data were first obtained from the Eco-SSL documents. These documents include all toxicity data with a score of at least 10 (see Data Extraction and Scoring section below) found from the literature search conducted as part of the Eco-SSL development process, even if there were not enough data points to derive an Eco-SSL. A literature search was then conducted for data published after the Eco-SSL publication dates for these five chemicals (2005 to 2007).

The literature search was conducted using the U.S. Department of Agriculture AGRICOLA database, the ECOTOXicology knowledgebase (ECOTOX) database, the U.S. National Library of Medicine's Toxicology Data Network (TOXNET), and Google Scholar. Only papers that met the Eco-SSL literature acceptance criteria were considered in deriving the soil screening levels (USEPA 2003a). In addition, only studies using the trivalent form of chromium were considered acceptable. Studies using the hexavalent form are not relevant because UCR soils are predominantly acidic (median and 95th percentile pH levels of 6.0 and 6.8, respectively) (Windward 2015) and acidic soils favor the transformation of hexavalent chromium to trivalent chromium (USEPA 2008).

Data extraction and scoring

Papers identified for antimony, arsenic, chromium, silver, and vanadium were reviewed to determine if any acceptable toxicity values were presented. Acceptable toxicity values included no-observed-adverse-effect concentrations (NOAECs), lowest-observed-adverse-effect concentration (LOAECs), or effect concentrations for 10 to 20% of the population (EC10 to EC20) (USEPA 2003b). If no acceptable toxicity values were presented in a paper, it was eliminated from further evaluation. In addition, only toxicity values presented as a concentration in soil were considered acceptable for deriving soil screening levels.

Each acceptable toxicity study was scored using nine study evaluation criteria from EPA (USEPA 2003b), as follows:

1) Testing was done under conditions of high bioavailability; bioavailability scores of 0, 1, or 2 were assigned based on the scoring matrix from EPA (2003b, Attachment A). Per USEPA (2003b), bioavailability was evaluated differently for cationic metals than for anionic metals (as described in the next section of this memo on derivation of soil screening levels; see footnote 5 on page 5).
2) Experimental designs for laboratory and field studies were documented and appropriate.
3) Concentration of test substance in soil was reported.
4) Control responses were acceptable.
5) Test was a chronic or life cycle test.
6) Chemical dosing procedure was reported and appropriate for chemical and test.
7) Dose-response relationship was reported or can be established from reported data.
8) The statistical tests used to calculate the benchmark and the level of significance were described.
9) The origin of the test organisms was described.

The methods for scoring are described in detail in Attachment A to the Eco-SSL standard operating procedure (SOP) No. 2 (USEPA 2003b). Studies that did not receive an overall score of at least 10 or a bioavailability score greater than zero were not considered further in the screening-level derivation process. Each criterion was allotted a maximum of 2 points.

If a paper reported toxicity data for more than one test species, chemical form, or soil type (including pH and organic matter [OM]), these data were considered to come from different studies for the purpose of deriving a soil screening level. Ecologically relevant endpoints for deriving Eco-SSLs are reproduction, population,[2] growth, biomass (plants only), and physiology (plants only), as specified by EPA and described in more detail in Table 1 of the SOP (USEPA 2003b).

For cobalt and molybdenum, chronic EC20s were compiled from the threshold calculator for metals in soil (ARCHE 2018). The soil toxicity data in the threshold calculator met relevance and reliability criteria put forth by Klimisch et al. (1997) and scoring systems for reporting and evaluating ecotoxicity data described in Moermond et al. (2016). Relevance and reliability requirements included:

1) Endpoints related to population-level effects (survival, growth, reproduction)
2) Testing of sensitive life stages
3) Complete description of test methods
4) Description of test soil characteristics
5) Analytical verification of test chemical concentrations or demonstration of nominal concentrations close to actual concentrations
6) Adequate control response and a clear concentration-response relationship.

Tests included in the threshold calculator, therefore, were considered to meet the minimum acceptability requirements for Eco-SSL calculations and were not scored (ARCHE 2018).[3]

Derivation of soil screening levels

The first step in deriving soil screening levels from the extracted data was to select a preferred toxicity value from a study if more than one value was presented for a particular species, soil type (including pH and OM), and chemical form. Using the methods outlined in the Eco-SSL guidance (USEPA 2003b), the following hierarchy was applied in selecting the preferred toxicity value:

EC20 > Maximum Acceptable Threshold Concentration (MATC)[4] > EC10

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[2] Population measures provided in Table 1 (USEPA 2003b) apply to a group of soil invertebrates of the same species occupying the same area at a given time, and include measures such as population density (number/area) and intrinsic population growth rate.

[3] The soil toxicity data included in the threshold calculator were evaluated relative to the Klimisch and Criteria for Reporting and Evaluating ecotoxicity Data (CRED) scoring systems (Klimisch et al. 1997; Moermond et al. 2016) and only those data in Category 1 (“Reliable without restrictions”) and Category 2 (“Reliable with restrictions”) were included (ARCHE 2018). Because the database went through extensive quality assurance/quality control review, additional review of the studies was not conducted as part of this evaluation.

[4] If only NOAEC and LOAEC values were presented for the study, the MATC was calculated as the geomean of the two values.

If a study reported toxicity values for more than one endpoint for a particular species, soil type, or chemical form, the following hierarchy from EPA (2003b) was applied for invertebrates:

Reproduction > Population > Growth

For plants, the most sensitive measurement of biomass production was selected. If biomass was measured in more than one way (i.e., shoot growth and root length), the most sensitive endpoint was selected (i.e., the endpoint with the lowest threshold).

The studies were then ranked by bioavailability score. Because the bioavailability of metals is influenced by pH and soil OM, a score of 0, 1 or 2 was assigned using a scoring matrix based on ranges of pH and OM (USEPA 2003b, Attachment A); [5] the higher score was associated with greater bioavailability. Bioavailability scoring differs for cationic metals and anionic metals, with the primary difference between the two being that cationic metals have a higher bioavailability score in acidic soils and anionic metals have a higher bioavailability score in less acidic soils. In this evaluation, arsenic, molybdenum, and vanadium were evaluated as anionic metals in soil, while the remaining were considered cationic metals in soil. Bioavailability scores were assigned to both the data from the reviewed literature and the data from the threshold calculator (ARCHE 2018); scores were already available for data from Eco-SSL documents.

At least three data points were needed to calculate a geomean for use as the soil screening level. If there were at least three data points with a bioavailability score of 2, all of the toxicity values with scores of 2 were used to calculate a geomean; none of the toxicity values with scores of 1 would be included.[6] If there were fewer than three data points with a bioavailability score of 2, all data points with bioavailability scores of 1 were added to the pool of data. For example, if there were two data points with scores of 2 and two data points with scores of 1, all four values would be used to calculate the geomean. For antimony, arsenic, chromium, silver, and vanadium, any acceptable data points from the literature reviews conducted in association with the Eco-SSL documents were also included in this step.

EPA's SOP for deriving plant and invertebrate Eco-SSL values (USEPA 2003b) requires at least three data points in order for the geomean calculated to be used as an Eco-SSL. In this document, the EPA method was modified so that soil screening levels could be

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[5] Per USEPA (2003b), cationic metals in natural soils were assigned a low bioavailability score of 0 if soil pH was >7 and OM was between 2 and 6 percent or if soil pH was ≥5.5 and OM was >6 percent. Anionic metals in natural soils were assigned a low bioavailability score of 0 if soil pH was ≤5.5 and OM was between 2 and 6 percent or if soil pH was <7 and OM was >10 percent.

[6] Studies excluded from the calculation of the geomean because of low bioavailability scores will be retained for potential use in the BERA. If hazard quotients indicate the potential for unacceptable risk for a particular metal using the Eco-SSLs or SSLs, then a bioavailability-based evaluation will be conducted using toxicity tests data from the excluded studies, or using ARCHE's threshold calculator (2018) for those metals included in the calculator. Bioavailability-based assessments are included as one of the steps in the proposed soil BERA approach (Windward 2019a).

derived if there were fewer than three data points. If only two data points were available, the lower value was selected as the soil screening level. Uncertainties associated with screening levels derived using only two data points are discussed in the Uncertainties section of this memorandum.

Lastly, the Eco-SSL guidance document (USEPA 2005c) indicates that preference in deriving the Eco-SSLs is given to studies with high bioavailability, and in general, metals in wetland soils are expected be less bioavailable because of the high organic content of the soil. As stated by EPA (2005c), Eco-SSLs are expected to be conservative for most soils including wetlands, and therefore may be useful for screening contaminants in wetland soils as long as they are not continuously inundated (i.e., sediments).

Results

Table 2 presents a list of papers reviewed, and whether data were considered acceptable for deriving a soil screening level and, if not acceptable, the rationale. The acceptable data points for deriving the soil screening levels based on the process described in the Methods section are presented in Table 3 and the calculated screening levels are presented in Table 4. The following subsections summarize the data used to calculate the screening level for each metal and receptor group.

Table 2. Non-Eco-SSL papers reviewed

Citation	Used to Derive Screening Level?	Reason Not Used to Derive Screening Level	Full Reference
Antimony and Plants			
Oorts et al. (2008)	yes	na	Oorts K, Smolders E, Degryse F, Buekers J, Gasco G, Cornelis G, Mertens J. 2008. Solubility and toxicity of antimony trioxide (Sb_2O_3) in soil. Environ Sci Tech 42:4378-4383.
Pan et al. (2011)	no	pH and organic matter not reported	Pan X, Zhang D, Chen X, Bao A, Li L. 2011. Antimony accumulation, growth performance, antioxidant defense system and photosynthesis of Zea mays in response to antimony pollution in soil. Wat Air Soil Pollut 215(1-4):517-523.
Tschan et al. (2009)	no	no data reported	Tschan M, Robinson BH, Nodari M, Schulin R. 2009. Antimony uptake by different plant species from nutrient solution, agar and soil. Environ Chem 6:144-152.
Tschan et al. (2010)	no	effect levels not relevant	Tschan M, Robinson B, Johnson CA, Burgi A, Schulin R. 2010. Antimony uptake and toxicity in sunflower and maize growing in SBIII and SBV contaminated soil. Plant Soil 334:235-245.
Zhao et al. (2015)	no	organic matter out of range	Zhao X, Zheng L, Xia X, Yin W, Lei J, Shi S, Shi X, Li H, Li Q, Wei Y, Chang E, Jiang Z, Liu J. 2015. Responses and acclimation of Chinese cork oak (*Quercus variabilis* Bl.) to metal stress: the inducible antimony tolerance in oak trees. Environ Sci Pollut Res 22(15):11456-11466.
Arsenic and Invertebrates			
Alves et al. (2018)	yes	na	Alves PRL, da Silva EB, Cardoso EJBN, Alleoni LRF. 2018. Ecotoxicological impact of arsenic on earthworms and collembolans as affected by attributes of a highly weathered tropical soil. Environ Sci Pollut Res 25:13217-13225.
Crouau and Moia (2006)	no	unacceptable low bioavailability score of 0	Crouau Y, Moia C. 2006. The relative sensitivity of growth and reproduction in the springtail, *Folsomia candida,* exposed to xenobiotics in the laboratory: an indicator of soil toxicity. Ecotoxicol Environ Saf 64:115-121.
Lin et al. (2019)	no	effect level not relevant	Lin X, Sun Z, Zhao L, Ma J, Li X, He F, Hou H. 2019. The toxicity of exogenous arsenic to soil-dwelling springtail *Folsomia candida* in relation to soil properties and aging time. Ecotoxicol Environ Saf 171:530-538.
Lock and Janssen (2002)	no	unacceptable low bioavailability score of 0	Lock K, Janssen CR. 2002. Toxicity of arsenate to the compostworm *Eisenia fetida*, the potworm *Enchytraeus albidus* and the springtail *Folsomia candida*. Bull Environ Contam Toxicol 68:760-765.

Table 2. Non-Eco-SSL papers reviewed

Citation	Used to Derive Screening Level?	Reason Not Used to Derive Screening Level	Full Reference
Chromium and Plants			
Baderna et al. (2015)	no	low bioavailability score (standard artificial soil receives score of 1 per USEPA [2003b] and sufficient data with higher bioavailability score are available)	Baderna D, Lomazzi E, Pogliaghi A, Ciaccia G, Lodi M, Benfenati E. 2015. Acute phytotoxicity of seven metals alone and in mixture: Are Italian soil threshold concentrations suitable for plant protection? Environ Res 140:102-111.
Bahrami et al. (2016)	no	OM not reported, no effects	Bahrami M, Heidari M, Ghorbani H. 2016. Variation in antioxidant enzyme activities, growth and some physiological parameters of bitter melon (*Momordica charantia*) under salinity and chromium stress. J Environ Biol 37:529-535.
Ding et al. (2014)	yes	na	Ding C, Li X, Zhang T, Ma Y, Wang X. 2014. Phytotoxicity and accumulation of chromium in carrot plants and the derivation of soil thresholds for Chinese soils. Ecotox Environ Saf 108:179-186.
do Nascimento et al. (2018)	no	OM not reported, no effect levels	do Nascimento JL, de Almeida A-AF, Barroso JP, Mangabeira PAO, Ahnert D, Sousa AGR, Silva JVS, Baligar VC. 2018. Physiological, ultrastructural, biochemical and molecular responses of young cocoa plants to the toxicity of Cr (III) in soil. Ecotox Environ Saf 159:272-283.
Fozia et al. (2008)	no	OM not reported, no effect levels	Fozia A, Muhammad AZ, Muhammad A, Zafar MK. 2008. Effect of chromium on growth attributes in sunflower (*Helianthus annuus* L.). J Environ Sci 20:1475-1480.
Lukina et al. (2016)	no	low bioavailability score (standard artificial soil receives score of 1 per USEPA [2003b] and sufficient data with higher bioavailability score are available)	Lukina AO, Boutin C, Rowland O, Carpenter DJ. 2016. Evaluating trivalent chromium toxicity on wild terrestrial and wetland plants. Chemosphere 162:355-364.
Su et al. (2005)	no	OM not reported, no effect levels	Su Y, Han FX, Sridhar BBM, Monts DL. 2005. Phytotoxicity and phytoaccumulation of trivalent and hexavalent chromium in brake fern. Environ Toxicol Chem 24(8):2019-2026.

Table 2. Non-Eco-SSL papers reviewed

Citation	Used to Derive Screening Level?	Reason Not Used to Derive Screening Level	Full Reference
UdDin et al. (2015)	no	OM not reported, no effect levels	UdDin I, Bano A, Masood S. 2015. Chromium toxicity tolerance of *Solanum nigrum* L. and *Parthenium hysterophorus* L. plants with reference to ion pattern, antioxidation activity and root exudation. Ecotox Environ Saf 113:271-278.
Wyszkowski and Radziemska (2010)	no	no effect levels	Wyszkowski M, Radziemska M. 2010. Effects of chromium (III and VI) on spring barley and maize biomass yield and content of nitrogenous compounds. J Toxicol Env Health Part A 73:1274-1282.
Silver and Invertebrates			
Bicho et al. (2016)	yes	na	Bicho RC, Ribeiro T, Rodrigues NP, Scott-Fordsmand JJ, Amorim MJB. 2016. Effects of Ag nanomaterials (NM300K) and Ag salt ($AgNO_3$) can be discriminated in a full life cycle long term test with *Enchytraeus crypticus*. J Haz Mat 318:608-614.
Diez-Ortiz et al. (2015)	no	effect level not relevant	Diez-Ortiz M, Lahive E, George S, Ter Schure A, Van Gestel CAM, Jurkschat K, Svendsen C, Spurgeon DJ. 2015. Short-term soil bioassays may not reveal the full toxicity potential for nanomaterials; bioavailability and toxicity of silver ions ($AgNO_3$) and silver nanoparticles to earthworm Eisenia fetida in long-term aged soils. Environ Pollut 203:191-198.
Mendes et al. (2015)	yes	na	Mendes LA, Maria VL, Scott-Fordsmand JJ, Amorim MJB. 2015. Ag nanoparticles (Ag NM300K) in the terrestrial environment: effects at population and cellular level in *Folsomia candida* (Collembola). Int J Environ Res Public Health 12:12530-12542.
Mendes et al. (2018)	no	effect level not relevant	Mendes LA, Maria VL, Scott-Fordsmand JJ, Amorim MJB. 2018. Multigenerational exposure of *Folsomia candida* to silver: effect of different contamination scenarios (continuous versus pulsed and recovery). Sci Tot Environ 631-632:326-333.
Schlich et al. (2013)	no	effect level not relevant	Schlich K, Klawonn T, Terytze K, Hund-Rinke K. 2013. Effects of silver nanoparticles and silver nitrate in the earthworm reproduction test. Environ Toxicol Chem 32(1):181-188.
Waalewijn-Kool et al. (2014)	yes	na	Waalewijn-Kool PL, Klein K, Fornies RM, van Gestel CAM. 2014. Bioaccumulation and toxicity of silver nanoparticles and silver nitrate to the soil arthropod *Folsomia candida*. Ecotoxicol 23:1629-1637.

Eco-SSL – ecological soil screening level

na – not applicable

OM – organic matter

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
Antimony and Plants									
Oorts et al. (2008)	1	antimony trioxide	*Lactuca sativa* cv. Pontiac	lettuce	7.0	1.6	shoot yield	EC10	4,505
Oorts et al. (2008)	1	antimony trioxide	*Hordeum vulgare* cv. Mauritia	summer barley	7.0	1.6	root elongation	EC10	1,948
								lowest value	*1,948*
Arsenic and Invertebrates									
Alves et al. (2018)	1	sodium arsenate	*Eisenia andrei*	oligochaete	6.1	5.24	number of juveniles	EC20	7.3
Alves et al. (2018)	1	sodium arsenate	*Folsomia candida*	springtail	6.1	5.24	number of juveniles	EC20	8.4
								lowest value	*7.3*
Chromium and Plants									
Ding et al. (2014)	2	chromium chloride	*Daucus carota*	carrot	4.84	0.9	yield (edible portion of plant)	MATC	199.3
Ding et al. (2014)	2	chromium chloride	*Daucus carota*	carrot	4.99	1.7	yield (edible portion of plant)	MATC	182.0
Ding et al. (2014)	2	chromium chloride	*Daucus carota*	carrot	5.35	1.5	yield (edible portion of plant)	MATC	182.8
Ding et al. (2014)	2	chromium chloride	*Daucus carota*	carrot	5.68	1.7	yield (edible portion of plant)	MATC	153.2

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
Ding et al. (2014)	2	chromium chloride	*Daucus carota*	carrot	6.83	1.0	yield (edible portion of plant)	MATC	211.0
Ding et al. (2014)	2	chromium chloride	*Daucus carota*	carrot	6.93	1.7	yield (edible portion of plant)	MATC	230.3
								geomean	*192*
Cobalt and Invertebrates[b]									
De Schamphelaere et al. (2008) as cited in ARCHE (2018)	2	cobalt chloride	*Folsomia candida*	springtail	4.4	2.1	number of juveniles per jar	EC20	28.2
De Schamphelaere et al. (2008) as cited in ARCHE (2018)	2	cobalt chloride	*Folsomia candida*	springtail	4.5	2.7	number of juveniles per jar	EC20	124.1
De Schamphelaere et al. (2008) as cited in ARCHE (2018)	2	cobalt chloride	*Folsomia candida*	springtail	4.7	3.7	number of juveniles per jar	EC20	219.3
De Schamphelaere et al. (2008) as cited in ARCHE (2018)	2	cobalt chloride	*Folsomia candida*	springtail	5.7	1.4	number of juveniles per jar	EC20	339.2
								geomean	*127*
Molybdenum and Plants[b]									
as cited in ARCHE (2018)	2	sodium molybdate	*Brassica napus*	rapeseed	6.7	1.5	yield (shoot)	EC20	11.8

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Brassica napus*	rapeseed	6.8	1.0	yield (shoot)	EC20	21.5
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Brassica napus*	rapeseed	7.3	2.2	yield (shoot)	EC20	30.5
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Brassica napus*	rapeseed	7.6	3.6	yield (shoot)	EC20	7.1
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Brassica napus*	rapeseed	7.8	1.4	yield (shoot)	EC20	5.2
Mico et al. (2007) as cited in ARCHE (2018)	2	sodium molybdate	*Hordeum vulgare*	barley	6.7	1.5	yield (root length)	EC20	63.2
Mico et al. (2007) as cited in ARCHE (2018)	2	sodium molybdate	*Hordeum vulgare*	barley	6.8	1.0	yield (root length)	EC20	1,325.3
Mico et al. (2007) as cited in ARCHE (2018)	2	sodium molybdate	*Hordeum vulgare*	barley	7.3	2.2	yield (root length)	EC20	37.7
Mico et al. (2007) as cited in ARCHE (2018)	2	sodium molybdate	*Hordeum vulgare*	barley	7.6	3.6	yield (root length)	EC20	53.7
Mico et al. (2007) as cited in ARCHE (2018)	2	sodium molybdate	*Hordeum vulgare*	barley	7.8	1.4	yield (root length)	EC20	8.5
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lolium perenne*	ryegrass	6.7	1.5	yield (shoot)	EC20	46.7

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lolium perenne*	ryegrass	6.8	1.0	yield (shoot)	EC20	167.2
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lolium perenne*	ryegrass	7.3	2.2	yield (shoot)	EC20	55.3
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lolium perenne*	ryegrass	7.6	3.6	yield (shoot)	EC20	28.2
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lolium perenne*	ryegrass	7.8	1.4	yield (shoot)	EC20	40.5
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lycopersicon esculentum*	tomato	6.7	1.5	yield (shoot)	EC20	46.7
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lycopersicon esculentum*	tomato	6.8	1.0	yield (shoot)	EC20	111.9
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lycopersicon esculentum*	tomato	7.3	2.2	yield (shoot)	EC20	18.0
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lycopersicon esculentum*	tomato	7.6	3.6	yield (shoot)	EC20	18.4
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Lycopersicon esculentum*	tomato	7.8	1.4	yield (shoot)	EC20	6.1
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Trifolium pratense*	red clover	6.7	1.5	yield (shoot)	EC20	45.4

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Trifolium pratense*	red clover	6.8	1.0	yield (shoot)	EC20	1.6
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Trifolium pratense*	red clover	7.3	2.2	yield (shoot)	EC20	22.5
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Trifolium pratense*	red clover	7.6	3.6	yield (shoot)	EC20	5.8
Mico et al. (2009) as cited in ARCHE (2018)	2	sodium molybdate	*Trifolium pratense*	red clover	7.8	1.4	yield (shoot)	EC20	9.3
								geomean	26.0
Molybdenum and Invertebrates[b,c]									
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Eisenia andrei*	oligochaete	6.7	1.5	number of juveniles per jar	EC20	37.1
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Eisenia andrei*	oligochaete	7.3	2.2	number of juveniles per jar	EC20	31.7
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Eisenia andrei*	oligochaete	7.6	3.6	number of juveniles per jar	EC20	64.4
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Eisenia andrei*	oligochaete	7.8	1.4	number of juveniles per jar	EC20	37.9
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Enchytraeus crypticus*	oligochaete	6.7	1.5	number of juveniles per jar	EC20	784.7
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Enchytraeus crypticus*	oligochaete	6.8	1.0	number of juveniles per jar	EC20	2,048.4

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Enchytraeus crypticus*	oligochaete	7.3	2.2	number of juveniles per jar	EC20	1,130.9
van Gestel et al. (2010) as cited in ARCHE (2018)	2	sodium molybdate	*Enchytraeus crypticus*	oligochaete	7.8	1.4	number of juveniles per jar	EC20	1,694.8
								geomean	233
Silver and Invertebrates									
Mendes et al. (2015)	2	silver nitrate	*Folsomia candida*	springtail	5.5	3.0	number of juveniles	EC20	76
Bicho et al. (2016)	2	silver nitrate	*Enchytraeus crypticus*	oligochaete	5.5	1.77	FLC reproduction @ 46 days	EC20	68
Bicho et al. (2016)	2	silver nitrate	*Enchytraeus crypticus*	oligochaete	5.5	1.77	ERT reproduction @ 21 days	EC20	47
Waalewijn-Kool et al. (2014)	2	silver nitrate	*Folsomia candida*	springtail	5.5	3.6	juveniles per jar	EC10	47.6
								geomean	58.3
Thallium and Plants									
Heim et al. (2002)	1	thallium carbonate	*Lepidium sativum*	garden cress	6.0	10	growth (roots)	MATC	31.6
Heim et al. (2002)	1	thallium carbonate	*Lepidium sativum*	garden cress	6.0	10	growth (shoots)	MATC	3.2
								lowest value	3.2
Thallium and Invertebrates									
Heim et al. (2002)	1	thallium carbonate	*Eisenia fetida*	earthworm	6.0	10	mortality	MATC	223.6

Table 3. Toxicity data used to derive soil screening levels

Reference	Bioavailability Score	Chemical Form	Scientific Name	Common Name	Soil pH	% OM	Endpoint	Type of Effect (Toxicity Parameter)	Effect Level/ Toxicity Value (mg/kg dw)[a]
Heim et al. (2002)	1	thallium carbonate	*Eisenia fetida*	earthworm	6.0	10	growth	MATC	70.7
Heim et al. (2002)	1	thallium carbonate	*Eisenia fetida*	earthworm	6.0	10	number of cocoons	MATC	22.4
Heim et al. (2002)	1	thallium carbonate	*Eisenia fetida*	earthworm	6.0	10	number of juveniles	MATC	2.2
Heim et al. (2002)	1	thallium carbonate	*Arianta arbustorum*	land snail	6.0	10	growth	MATC	31.6
								geomean	30.2
Vanadium and Invertebrates									
Environment Canada (1995) as cited in Environment Canada (1999)	1	vanadium pentoxide	*Eisenia fetida*	earthworm	4.2-4.3	5.6	mortality	MATC	294

[a] If wet weight or dry weight was not specified in the data source, dry weight was assumed.

[b] Because the ARCHE database went through extensive quality assurance/quality control review (ARCHE 2018), additional review of the studies for cobalt and molybdenum was not conducted as part of this evaluation.

[c] One test result for *Eisenia andrei* (bioavailability score of 2 and EC20 of 1,299 mg/kg) was excluded because of control performance issues (ARCHE 2018). The mean control reproduction in this test was 5.8 juveniles per jar, while controls in the other tests had mean control reproduction ranging from 37.3 to 97.3 juveniles per jar.

EC10 – effect concentrations for 10% of the population

EC20 – effect concentrations for 20% of the population

ERT – enchytraeid reproduction test

FLC – full life cycle test

MATC – maximum acceptable toxicant concentration

nr – not reported

OM – organic matter

Table 4. Calculated soil screening levels

Metal	Soil Screening Level (mg/kg dw)			
	Plants	Data Points Used to Derive Screening Level	Invertebrates	Data Points Used to Derive Screening Level
Antimony	1,900[a]	2 EC10s	not needed[b]	not applicable
Arsenic	not needed[c]	not applicable	7.3[a]	2 EC20s
Chromium	190	6 MATCs	not needed[b]	not applicable
Cobalt	not needed[c]	not applicable	130	4 EC20s
Molybdenum	26	25 EC20s	233	8 EC20s
Silver	not needed[b]	not applicable	58	3 EC20s; 1 EC10
Thallium	3.2[a]	2 MATCs	30	5 MATCs
Vanadium	not needed[b]	not applicable	294	1 MATC[d]

Note: Two significant figures are used for the soil screening levels.

[a] These soil screening levels were not derived using EPA's SOP for deriving plant and invertebrate Eco-SSLs, because there were not at least three data points available to calculate a geomean; instead the lower of the two data points was selected

[b] A soil screening level is not needed because the metal is not a COPC for the receptor indicated.

[c] A soil screening level is not needed because there is an Eco-SSL value.

[d] The vanadium soil screening level for invertebrates was not derived using EPA's SOP for deriving an Eco-SSL because the unpublished study was not available to review the study evaluation criteria, and because at least three data points were not available to calculate a geomean.

EC10 – effect concentrations for 10% of the population
EC20 – effect concentrations for 20% of the population
Eco-SSL – ecological soil screening level
EPA – US Environmental Protection Agency
MATC – maximum acceptable threshold concentration
mg/kg dw – milligrams per kilogram dry weight
SOP – standard operating procedure

Antimony

Only two datasets were acceptable to derive a soil screening level for antimony and plants. The screening level of 1,900 mg/kg for barley growth shown in Table 4 is based on the lower of two EC10s from Oorts et al. (2008). There were no acceptable data points in the Eco-SSL document (USEPA 2005a).

Arsenic

Only two datasets were acceptable to derive a soil screening level for arsenic and invertebrates. The screening level of 7.3 mg/kg shown in Table 4 is based on the lower of two EC20s from Alves et al. (2018). The effect is for oligochaete reproduction in soil with a bioavailability score of 1. There were no acceptable data points in the Eco-SSL document (USEPA 2005b).

Chromium

For plants, the screening level of 190 mg/kg shown in Table 4 is based on the geomean of six MATCs from Ding et al. (2014). The effects are for carrot growth (i.e., yield) in six soil types with bioavailability scores of 2. There were no acceptable data points for plants in the Eco-SSL document (USEPA 2008).

Cobalt

For invertebrates, the screening level of 130 mg/kg shown in Table 4 is based on the geomean of four EC20s from the threshold calculator (ARCHE 2018). The effects are for springtail reproduction in four soil types with bioavailability scores of 2. The threshold calculator included additional acceptable data points, but they were not used in deriving a screening level because they had bioavailability scores of less than 2 and there were at least three data points with scores of 2.

Molybdenum

For plants, the screening level of 26 mg/kg shown in Table 4 is based on the geomean of 25 EC20s from the threshold calculator (ARCHE 2018). The effects are for rapeseed, barley, ryegrass, tomato, and red clover growth (i.e., yield) in five soil types with bioavailability scores of 2.

For invertebrates, the screening level of 233 mg/kg shown in Table 4 is based on the geomean of 8 EC20s from the threshold calculator (ARCHE 2018). The effects are for oligochaete reproduction (i.e., number of juveniles) in different soils with bioavailability scores of 2. There was a ninth oligochaete test with a bioavailability score of 2 and an EC20 of 1,299 mg/kg, but it was excluded due to low control performance.

Additional acceptable data for plants and invertebrates were included in the threshold calculator (ARCHE 2018), but these had bioavailability scores of less than 2 and were not used in deriving a screening level because there were at least three data points with scores of 2.

Silver

For invertebrates, the screening level of 58 mg/kg shown in Table 4 is based on the geomean of one EC20 from Mendes et al. (2015), two EC20s from Bicho et al. (2016), and one EC10 from Waalewijn-Kool et al. (2014). The effects are for springtail and oligochaete reproduction in soils with bioavailability scores of 2. There were no acceptable data points in the Eco-SSL document (USEPA 2006).

Thallium

For plants, only two datasets were available to derive a soil screening level. The screening level of 3.2 mg/kg for garden cress growth shown in Table 4 is based on the lower of the two MATCs from Heim et al. (2002).

For invertebrates, the screening level of 30 mg/kg shown in Table 4 is based on the geomean of 5 MATCs from Heim et al. (2002). The effects are for earthworm mortality, growth, and reproduction and land snail growth in artificial soil with a bioavailability score of 1.

Vanadium

For invertebrates, toxicity data were available from only one study, although the original paper was unpublished and not available for review (Environment Canada

(1995), as cited in Environment Canada (1999)). Because this study could not be reviewed, information on some of the nine study evaluation criteria was not available. However, these data were used to derive the soil screening level because of the lack of any other data for vanadium, and because the study was considered acceptable by Environment Canada in deriving their soil quality guideline for vanadium. The soil screening level of 294 mg/kg is based on earthworm mortality in soil with a bioavailability score of 2.

UNCERTAINTIES

Key uncertainties in calculating the soil screening levels are associated with sample size limitations, the range of available toxicity values, representativeness of tested species, the range of soil types tested, the representativeness of the endpoints tested, and uncertainty about bioavailability in tested soils. In general, soil screening levels derived using a greater number of data points that encompass a variety of species, soil types, and endpoints are more likely to represent the average toxicity over a range of conditions than those calculated using limited data. However, there is some uncertainty associated with soil screening levels that are based on a large range of toxicity values (i.e., molybdenum for plants and invertebrates).

Soil screening levels for antimony/plants, arsenic/invertebrates, and thallium/plants are more uncertain than those for the other metals in this document. For antimony/plants and thallium/plants, only two acceptable data points were available, the bioavailability score was 1, and only one species was represented. Similarly, for arsenic/invertebrates, two acceptable data points were available and the bioavailability score was 1, but data for two species were available. Soil screening levels for other metal/receptor combinations were derived from at least four data points with bioavailability scores of 2. There is also some uncertainty associated with soil screening levels for chromium/plants and cobalt/invertebrates because only one species was represented. It is unknown whether these uncertainties due to limited toxicity data may lead to the over- or underestimation of soil screening levels, as it depends on whether the species tested for each metal are representative of sensitive species.

The vanadium/invertebrate soil screening level is uncertain because only one data point was available. In addition, the unpublished study was not available for review, although it is presumably of acceptable quality because it was used by Environment Canada to derive the soil quality guideline for vanadium.

In addition, there is uncertainty created by using different effect levels (e.g., EC10, EC20, and MATC). The preferred effect level is 20%, following EPA guidance (USEPA 2005c). Thus, the use of EC10s is conservative relative to the use of EC20s, whereas the use of MATCs may under- or over-predict the 20% effect level depending on the effect levels associated with the NOAEC and LOAEC used to derive the MATC.

SUMMARY

EPA's Eco-SSL guidance was used to derive soil screening levels for metals without Eco-SSL values. Toxicity data used to derive the soil screening levels were obtained from a literature search, from the threshold calculator (ARCHE 2018), and from the Eco-SSL documents. Soil screening levels were derived for antimony (plants), arsenic (invertebrates), chromium (plants), cobalt (invertebrates), molybdenum (plants and invertebrates), silver (invertebrates), and thallium (plants and invertebrates).

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ATTACHMENT G2

PLANT AND INVERTEBRATE SOIL BENCHMARKS FOR USE IN THE UPPER COLUMBIA RIVER BASELINE ECOLOGICAL RISK ASSESSMENT

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MEMORANDUM

To: Teck American Incorporated

From: Windward Environmental LLC

Subject: Plant and Invertebrate Soil Benchmarks for Use in the Upper Columbia River Baseline Ecological Risk Assessment

Date: April 2024

1 INTRODUCTION

This technical memorandum describes the benchmarks that are used in the Upper Columbia River (UCR) baseline ecological risk assessment (BERA) for the evaluation of risk to plants and invertebrates from the soil exposure pathway. Two types of benchmarks are used:

- U.S. Environmental Protection Agency (EPA) ecological soil screening levels (Eco-SSLs) for plants and invertebrates, or soil screening levels (SSLs) developed for use in the BERA for metals without Eco-SSLs (Attachment G1)
- Bioavailability-adjusted benchmarks derived from the Threshold Calculator for metals in soil developed by Oorts (2020)

Section 2 of this memorandum presents the metals identified for evaluation in the BERA based on the *Chemicals of Potential Concern Refinement for Aquatic and Terrestrial Receptors* (TAI 2019, 2020) (hereinafter referred to as the COPC refinement). Sections 3 and 4 of this memorandum present the Eco-SSLs and SSLs and the bioavailability-adjusted benchmarks from the Threshold Calculator, respectively. Section 5 summarizes preliminary remediation goals (PRGs) previously developed for soil at the Hanford site in south-central Washington (approximately 200 miles downstream from the Grand Coulee Dam); these PRGs were used to provide regional context for the bioavailability-adjusted benchmarks derived from the Threshold Calculator.

2 METALS FOR EVALUATION IN THE BERA

The COPC refinement (TAI 2019, 2020) identified a metal as a COPC for plants or invertebrates if that metal had more than one exceedance of its Eco-SSL (Table 1). Metal/receptor combinations that had only one exceedance or that had no benchmarks were identified as chemicals of interest (COIs) that would be evaluated in more depth in the BERA. The remaining metal/receptor combinations that did not screen in as COPCs were eliminated from further evaluation. Metal/receptor combinations identified as COPCs or COIs in Table 1 are further evaluated in the BERA using benchmarks presented in this memorandum.

Table 1. COPC refinement results for metals

Metal	Terrestrial Plants	Terrestrial Invertebrates
Aluminum	COPC	COPC
Antimony	retained as COI[a]	not a COPC
Arsenic	COPC	retained as COI[a]
Barium	COPC[b,c]	COPC
Beryllium	not a COPC	not a COPC
Cadmium	not a COPC	not a COPC
Chromium	retained as COI[a]	retained as COI[c,d]
Cobalt	COPC	retained as COI[a]
Copper	COPC	COPC
Iron	COPC	COPC
Lead	COPC	not a COPC
Manganese	COPC	COPC
Mercury	not a COPC	not a COPC
Molybdenum	retained as COI[a]	retained as COI[a]
Nickel	COPC	not a COPC
Selenium	COPC	not a COPC
Silver	not a COPC	retained as COI[a]
Thallium	retained as COI[a]	retained as COI[a]
Vanadium	not a COPC	retained as COI[a]
Zinc	COPC	COPC

[a] Retained as a COI because no benchmark (i.e., Eco-SSL) was available.

[b] Barium was originally identified as a COI in the COPC refinement but is now identified as a COPC based on rationale described in the text directly below this table (TAI 2019, 2020).

[c] Eco-SSLs value could not be developed for barium (USEPA 2005) or chromium (USEPA 2008), because toxicity data were insufficient (i.e., the minimum of three toxicity studies were not available). Therefore, the benchmarks used in the COPC refinement were derived from the lowest available acceptable toxicity values presented in the Eco-SSL documents.

[d] Retained as a COI because there was only one exceedance of the benchmark.

COI – chemical of interest

COPC – chemical of potential concern

Eco-SSL – ecological soil screening level

It should be noted that barium was identified as a COI for plants in the COPC refinement (TAI 2019, 2020), because there was only one exceedance of the benchmark using the mean value at locations where three triplicate soil variability samples were collected during the 2014 UCR Upland Soil Study (TAI 2015). If the individual triplicate values are used instead, there are two exceedances of the benchmark. Based on this observation, EPA requested that barium be retained for the BERA as a COPC for plants (USEPA 2020).

3 SOIL SCREENING LEVEL BENCHMARKS

Eco-SSLs are used as soil benchmarks in the BERA if they are available. For metals and receptors that were not evaluated in the COPC refinement (TAI 2019, 2020) because they lacked Eco-SSLs, as shown in Table 1, TAI developed SSLs for use in the BERA following the same methods used by EPA to derive the Eco-SSLs (USEPA 2003d). The methods used to compile toxicity data, extract data from papers, score studies based on acceptability criteria, and derive screening levels from the acceptable data are described in detail in a technical memorandum from Teck American Incorporated (TAI) to EPA (Attachment G1).[1] Briefly, studies received scores of 0, 1, or 2 for bioavailability, as determined by pH and organic matter (OM) content, a score of 2 representing the greatest bioavailability. Only studies with bioavailability scores of 1 or 2 were used to derive SSLs. Acceptable toxicity effect levels for use in deriving SSLs were the maximum acceptable threshold concentration (MATC)[2] and effect concentrations for 10 or 20% of the test population (EC10s or EC20s) (USEPA 2003a). Additional details on the derivation of the EPA-approved SSLs for use in the UCR BERA are described in the SSL development technical memorandum (Attachment G1).

Two metal/receptor combinations (barium/plants and chromium/invertebrates) were not included in the SSL development technical memorandum (Attachment G1). Therefore, the methods described in Attachment G1 were used to derive SSLs for these two metal/receptor combinations. Although Eco-SSL documents were prepared for barium and chromium, Eco-SSL values could not be derived for barium/plants or chromium/invertebrates because of an insufficient number of studies. The literature search for studies conducted after publication of the Eco-SSL documents resulted in the identification of one potentially acceptable paper for barium/plants (Melo et al. 2011), which was reviewed and scored based on the nine acceptability criteria described in Attachment G1. Melo et al. (2011) received an overall score of less than 10, so it could not be used in SSL derivation. As a result, the lowest toxicity values presented in the Eco-SSL documents were selected as SSLs, as follows:

- Barium/plants: 1,414 mg/kg, based on the toxicity value from Chaudhry et al. (1977), as cited in Table 3.1 of the barium Eco-SSL document (USEPA 2005)

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[1] EPA approved this approach memorandum via email on February 11, 2020.

[2] The MATC is the geomean of the no-observed-adverse-effect concentration (NOEC) and the lowest-observed-adverse-effect concentration (LOEC).

- Chromium/invertebrates: 57 mg/kg, based on identical toxicity values from van Gestel et al. (1993) and van Gestel et al. (1992), as cited in Table 4.1 of the chromium Eco-SSL document (USEPA 2008)

For arsenic/invertebrates, a recent study (Lin et al. 2019) was found that was not available in the spring of 2019, when the literature search had been conducted for the development of SSLs (Attachment G1). The SSL of 7.3 mg/kg dry weight (dw) (Attachment G1) was derived as the lesser of only two toxicity values available at the time, both of which were from a study by Alves et al. (2018). The Alves et al. (2018) study conducted 28-day reproduction toxicity tests with both springtail (*Folsomia candida*) and earthworm (*Eisenia andrei*) using a soil type with a bioavailability score of 1 (moderate level) based on EPA's bioavailability scoring matrix (USEPA 2003d). The more recent Lin et al. (2019) study investigated not only the effects of soil pH and OM content on arsenic bioavailability and toxicity, but also the effects of soil aging, which is an important variable affecting metal bioavailability. Ten different soils with pHs ranging from 4.9 to 8.4 and OM ranging from 1.1 to 4.6% were evaluated for toxicity to springtail (Lin et al. 2019). Using EPA's bioavailability scoring matrix (USEPA 2003d), six soils had a score of 1 (moderate level) and four soils had a score of 2 (high level). Soils were spiked with sodium arsenate and then aged for 150 days prior to conducting 28-day reproduction toxicity tests. Toxicity results from Lin et al. (2019) were presented as NOECs and LOECs, allowing for the calculation of an MATC for each soil type. If the Lin et al. (2019) study had been available at the time of SSL development, the SSL would have been calculated as 153 mg/kg dw according to EPA's Eco-SSL methods (i.e., the geomean of the preferred toxicity values for soils with the highest bioavailability score).[3] Therefore, the value of 153 mg/kg dw is used as the SSL for arsenic/invertebrates in this evaluation.

The Eco-SSLs and SSLs for metal/receptor combinations evaluated in the BERA are listed in Table 2. EPA did not develop Eco-SSLs for aluminum or iron because measurements of total concentrations of those metals in soils are not suitable or reliable for the prediction of potential toxicity. The aluminum and iron Eco-SSL documents recommend identifying these metals as COPCs if the soil pH is less than 5.5 or 5.0, respectively (USEPA 2003b, c).

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[3] The soils with the highest bioavailability scores were the four soils from Lin et al. (2019) with scores of 2; the MATCs for these soils were 480, 480, 12, and 20 mg/kg.

Table 2. Soil screening levels for metals and receptors evaluated in the BERA

Metal	Plants		Invertebrates	
	Screening Level (mg/kg dw)	Type of Screening Level	Screening Level (mg/kg dw)	Type of Screening Level
Aluminum	pH < 5.5	Eco-SSL	pH < 5.5	Eco-SSL
Antimony	1,900	SSL	not a COPC	na
Arsenic	18	Eco-SSL	153	SSL
Barium	1,414	SSL	330	Eco-SSL
Chromium	190	SSL	57	SSL
Cobalt	13	Eco-SSL	130	SSL
Copper	70	Eco-SSL	80	Eco-SSL
Iron	pH < 5.0	Eco-SSL	pH < 5.0	Eco-SSL
Lead	120	Eco-SSL	not a COPC	na
Manganese	220	Eco-SSL	450	Eco-SSL
Molybdenum	26	SSL	233	SSL
Nickel	38	Eco-SSL	not a COPC	na
Selenium	0.52	Eco-SSL	not a COPC	na
Silver	not a COPC	na	58	SSL
Thallium	3.2	SSL	30	SSL
Vanadium	not a COPC	na	294	SSL
Zinc	160	Eco-SSL	120	Eco-SSL

BERA – baseline ecological risk assessment
COPC – chemical of potential concern
Eco-SSL – ecological soil screening level
mg/kg dw – milligram per kilogram dry weight
na – not applicable
SSL – soil screening level

4 BIOAVAILABILITY-ADJUSTED BENCHMARKS

Bioavailability-adjusted benchmarks were calculated using the Threshold Calculator for metals in soil (Oorts 2020). This tool includes data on the chronic toxicity of seven metals (cadmium, cobalt, copper, lead, molybdenum, nickel, and zinc) to plants and invertebrates. In developing the Threshold Calculator, soil properties that may have an important influence on metals bioavailability and toxicity—namely, organic carbon (OC) content, pH, clay content, and cation exchange capacity (CEC)—were also compiled for each toxicity test. For those plant and invertebrate species tested over a wide range of soil bioavailability conditions, empirical regression relationships between metal toxicity and one or more soil parameters were developed (Oorts 2020). For divalent cationic metals, increased OC content, pH, clay content, and CEC reduce metal bioavailability in soil. For oxyanions such as molybdenum, bioavailability is greater at higher pH.

For this evaluation, the Threshold Calculator was used to adjust all toxicity values in its database to the relevant soil conditions at each UCR sampling location (i.e., benchmarks were calculated on a sample-by-sample basis based on measured soil conditions in each sample). The Threshold Calculator requires that pH be reported using the 0.01 molar (M) calcium chloride ($CaCl_2$) method and that CEC be reported as effective CEC (eCEC)[4] (Oorts 2020). In the 2014 UCR Upland Soil Study, however, pH was measured using the water method and CEC was measured rather than eCEC (TAI 2015). Following Oorts (2020), pH based on the 0.01 M $CaCl_2$ method was estimated from the water method as follows:

$$\text{pH (0.01 M } CaCl_2 \text{ method)} = -0.54 + 1.00 \times \text{pH (water method)} \qquad \textbf{Equation 1}$$

The eCEC was calculated from pH, %clay, and OC using the following equation (Oorts 2020):

$$\text{eCEC (cmolc/kg)} = (30 + 4.4 \times \text{pH}) \times \%\text{Clay}/100 + (-59 + 51 \times \text{pH}) \times \%\text{OC}/100 \qquad \textbf{Equation 2}$$

The toxicity values were defined as the effect concentrations causing a 20% effect (EC20s), which is consistent with the chronic effect level used to develop ambient water quality criteria (AWQC) (USEPA 2013, 2016). This process resulted in a species sensitivity distribution (SSD) of EC20s adjusted to the relevant bioavailability condition at each location. The bioavailability-adjusted benchmark was then calculated as the 5th percentile of the SSD on a location-specific basis. This approach is analogous to EPA's approach to calculating hardness-based AWQC, which entails the application of a hardness-based bioavailability model to adjust toxicity data in the SSD to a water hardness of interest; the 5th percentile of the SSD is then calculated to derive the criterion.

The following bullets summarize the user-defined selections in the Input+Output tab of the Threshold Calculator. Note that each Threshold Calculator "run" is composed of a single metal and trophic level of interest (e.g., plants):

- Select metal: A dropdown menu allows for selection of the metal of interest.
- Select trophic levels to be protected: A dropdown menu provides various options, but plants and invertebrates were of interest for the present evaluation; each was run separately to derive a bioavailability-adjusted plant benchmark and a bioavailability-adjusted invertebrate benchmark.
- Enter effect level (x in ECx): "20" was entered because the effect level of interest was the EC20.
- Enter the probability level (p in HCp): "5" was entered because the 5th percentile of the SSD was of interest.
- Use NOEC, MATC, and LOEC values in case no reliable ECx value can be derived: "Yes" was selected in the dropdown menu to maximize the amount of

[4] The eCEC is measured at the existing pH of the soil, while the CEC is measured at a buffered pH (e.g., pH 7).

toxicity information and species included in the SSD. The default upper effect boundaries of 10% for the NOEC, 25% for the MATC, and 40% for the LOEC were retained. These boundaries ensured that the values did not deviate substantially from the target effect level of 20%.

- Total or added metal approach: The total metal approach was selected, meaning that total metals concentrations were used to characterize metals concentrations in the soil toxicity tests used to identify the EC20s (and NOECs, LOECs, and MATCs in the absence of an EC20 for a given test). The use of total metals concentrations accounts for the background concentrations of the metals in the tested soils. In comparing site soil concentrations to the benchmarks, total metals concentrations are applied (the same approach for comparing site soil concentrations to Eco-SSLs).[5]
- Jurisdiction: The "open/global" option was selected so as not to be constrained by European chemical registration requirements (i.e., the other option in the Threshold Calculator).

The Threshold Calculator also includes a Lab-field and Assessment Factor tab. A lab-field factor provides a correction for aging and leaching processes, or for aging processes only if it was not necessary to account for leaching processes. Leaching processes are corrected for in toxicity tests conducted with soils freshly spiked with metal, as the change in ionic strength and pH of the freshly spiked soils increases metal bioavailability relative to the bioavailability that would be observed in a natural soil. The default lab-field factors in the Threshold Calculator were retained. These factors were based on a weight of evidence that considered both the changes in metal toxicity with long-term equilibration (aging) or leaching of excess ions and changes in metal behavior in soil (e.g., pore water concentrations, E-values[6]) (Oorts 2020). Assessment factors in the Threshold Calculator were not applied, as these are policy-based factors applicable to the European Union REACH program for chemical registration and thus not relevant to the UCR.

Based on the Threshold Calculator selections described above, the Multiple Soil-specific Input tab was used to develop bioavailability-adjusted benchmarks for the metals to be evaluated in the BERA that are included in the Threshold Calculator, and for all soil samples assessed in the Aquatic BERA with sufficient data for bioavailability

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[5] The added metal approach entails subtracting background metals concentrations from both the soil toxicity tests used to derive the bioavailability-adjusted benchmarks and site soils. If the background concentration of a given metal at a site is greater than the background concentration of that metal in the toxicity tests that are the "drivers" of the bioavailability-adjusted benchmark, then the total metal approach would err toward conservatism. The opposite would be true if a site had a lower background concentration of that metal relative to the toxicity tests that were drivers of the bioavailability-adjusted benchmark.

[6] The E-value is a measure of the isotopically exchangeable metals fraction, which provides a measure of the metals pool that is potentially bioavailable in an aged soil (Ma et al. 2006; OECD 2016).

parameters. In addition to the bioavailability-adjusted benchmark, the Threshold Calculator provides the potentially affected fraction (PAF) for each sample. The PAF is derived based on the measured metal concentration in the sample relative to the bioavailability-adjusted SSD for that sample (i.e., the same bioavailability-adjusted SSD from which the 5th percentile is used to derive the benchmark). For example, if the measured concentration of a metal falls at the 20th percentile of its respective SSD, the PAF is 20% (i.e., 20% of the species are estimated to have an EC20 less than the measured metal concentration). Thus, while a hazard quotient (HQ) provides information on how the measured metal concentration compares to its benchmark, the PAF accounts for the slope (or steepness) of the SSD by providing additional information on the estimated percentage of species with EC20s exceeded by the measured metal concentration (e.g., an HQ of 3 based on an SSD with a steep slope will have a higher PAF than an HQ of 3 based on an SSD with a shallower slope).

The BERA metals (and receptors) in the Threshold Calculator are cobalt (plants, invertebrates), copper (plants, invertebrates), lead (plants), molybdenum (plants, invertebrates), nickel (plants), and zinc (plants, invertebrates). For cobalt, copper, lead, nickel, and zinc, the bioavailability models are based on eCEC (and both eCEC and pH for zinc/plants); for molybdenum, the bioavailability models are based on clay and pH for plants and just clay for invertebrates. The types of endpoints and species included in the Threshold Calculator for BERA metal/receptor combinations are presented in Table 3, including the most sensitive species with the lowest EC20s that drove the SSD used to derive the bioavailability-adjusted benchmark.

Table 3. Data used in the Threshold Calculator to calculate bioavailability-adjusted benchmarks for metals and receptors evaluated in the BERA

Metal	Endpoints	Number and Type of Species	Most Sensitive Species and Endpoints
Plants			
Cobalt	yield (roots, shoots)	7 species of grasses, flowering plants, and root vegetables	clover (root yield); alfalfa (shoot yield)
Copper	mortality, reproduction, seedling emergence, yield (seeds, roots, and shoots)	10 species of grasses and flowering plants	tomato (shoot yield); barley grass (root length yield)
Lead	net photosynthesis, yield (roots, shoots, total plant)	16 species of grasses, flowering plants, and evergreen trees	barley grass (shoot yield); tomato (shoot yield)
Molybdenum	yield (shoots, roots)	5 species of grasses and flowering plants	rapeseed (shoot yield); tomato (shoot yield); clover (shoot yield)
Nickel	yield (seeds, roots, shoots)	11 species of grasses and flowering plants	tomato (shoot yield); spinach (shoot yield)
Zinc	first bloom, yield (seeds, roots, shoots)	18 species grasses, flowering plants, and root vegetables	red clover (root and shoot yield); barley grass (shoot yield)
Invertebrates			
Cobalt	reproduction	4 species of oligochaete worms and springtails	oligochaete worms (reproduction)
Copper	growth, reproduction, mortality, litter breakdown	14 species of oligochaete worms, springtails, mites, and nematodes	oligochaete worm (reproduction); springtail (reproduction)
Molybdenum	reproduction	3 species of oligochaete worms and springtails	oligochaete worms (reproduction)
Zinc	growth and reproduction	9 species of oligochaete worms and springtails	springtail (reproduction); oligochaete worm (reproduction)

BERA – baseline ecological risk assessment

5 Hanford Soil Bioassay Data for Use in Uncertainty Evaluations

The Hanford soil PRGs were not identified as plant and invertebrate soil benchmarks for use in the BERA, but they do provide regional context for the other soil benchmarks. For example, PRGs were developed in part from Hanford soil bioassays with test species that were considered regionally relevant for that purpose. Also, the Hanford PRGs provide an example of the importance of soil aging in assessing metals toxicity; this is a primary uncertainty in the Eco-SSLs/SSLs, which are based almost exclusively on toxicity tests in which metal salts were spiked into soils and the soils were not aged prior to testing. Lastly, the Hanford bioassay results and resulting PRGs are useful for evaluating the applicability, and potential conservatism, of the bioavailability-adjusted benchmarks for the soils in the region. The following summarizes the basis for the

Hanford PRGs and how they may help inform the soil benchmarks based on Eco-SSLs/SSLs and bioavailability-adjusted benchmarks.

Development of the Hanford PRGs followed an iterative framework that adhered to the steps outlined in *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments: Interim Final* (USEPA 1997) and was intended to protect a wide range of receptors from adverse effects (CH2M HILL 2014). Tier 1 PRGs were based on screening benchmarks such as Eco-SSLs, but Tier 2 PRGs were developed when Tier 1 PRGs were exceeded at both remediated and unremediated waste sites (CH2M HILL 2012). The following paragraphs summarize 1) the basis for the Hanford Tier 2 PRGs and 2) the potential applicability of these PRGs to UCR soils based on a provided comparison of bioavailability conditions.

Terrestrial plant and invertebrate PRGs were developed for the Hanford site based on results from site-specific bioassays (CH2M HILL 2012). Two types of site-specific bioassays were conducted for the Phase 2 Hanford evaluation using soils representing concentrations found throughout the River Corridor and Central Plateau areas of the site: 1) Sandberg bluegrass (*Poa secunda*) 28-day germination and growth, and 2) springtail 28-day reproduction and survival (CH2M HILL 2012). These bioassays were conducted on a subset of 59 soil samples representing a range of concentrations and environmental conditions (e.g., pH and OC content) found across the site. In addition, bioassays conducted on 11 samples from the Old Orchards area were considered in the development of PRGs. These bioassays consisted of 14-day tests with lettuce (growth and survival) and earthworms (survival and morphological and behavioral alterations) (Ecology 2011).

Because all of the site-specific thresholds from the bioassays were NOECs, the selected PRGs were based on the highest site-specific thresholds with the lowest uncertainty. For some metals and receptors, soil concentrations tested were below background or below the range of interest, in which case other data were used to derive the PRGs, including Eco-SSLs, arsenic and lead SSLs from the Washington State Department of Ecology (Ecology) (2011), soil ecological indicator concentrations from Ecology (Washington Administrative Code [WAC] 173-340, Table 749-3), values published by Oak Ridge National Laboratory (Efroymson et al. 1997a; Efroymson et al. 1997b), or site-specific background (CH2M HILL 2012). Only PRGs derived from the Hanford bioassays were used to facilitate interpretation of Eco-SSLs/SSLs and bioavailability-adjusted benchmarks in the UCR BERA, as shown in Table 4.

Table 4. Hanford bioassay-based PRGs for metals and receptors evaluated in the BERA

Metal	Bioassay-based PRG (mg/kg dw)
Plants	
Aluminum	na[a]
Antimony	842

Metal	Bioassay-based PRG (mg/kg dw)
Arsenic	128
Barium	na[b]
Chromium	259
Cobalt	na[b]
Copper	na[c]
Iron	na[a]
Lead	9,090
Manganese	1,260
Molybdenum	na[c]
Nickel	na[b]
Selenium	2.02
Thallium	na[b]
Zinc	621
Invertebrates	
Aluminum	na[a]
Arsenic	128
Barium	358
Chromium	149
Cobalt	na[b]
Copper	58
Iron	na[a]
Manganese	1,260
Molybdenum	28
Silver	2.99
Thallium	0.459
Vanadium	116
Zinc	8,980

a Hanford PRG was not derived.

b PRG was not based on Hanford bioassays because the tested soil concentrations were below background and/or range of interest.

c PRG was not based on Hanford bioassays because analyses were considered incomplete.

BERA – baseline ecological risk assessment

mg/kg dw – milligrams per kilogram dry weight

na – not available

PRG – preliminary remediation goal

In order to evaluate the relevance of using Hanford PRGs to facilitate interpretation of benchmarks in the UCR Upland and Aquatic BERAs, it was important to understand how metal bioavailability conditions in Hanford soils compare to those in UCR soils (e.g., if Hanford soils have lower bioavailability conditions for metals than do UCR soils, the Hanford PRGs would not be a useful point of comparison for UCR soils). To compare the metal bioavailability conditions of Hanford and UCR soils, first a principal component analysis (PCA) was conducted based on important bioavailability parameters (i.e., CEC, total organic carbon, pH, and %clay). The UCR soil data evaluated were those that form the data set for the Relict Floodplan Deposition Area (RFDA) and Windblown Sediment Deposition Area (WSDA) BERA in Volume 4 of the Aquatic BERA for the UCR site. Sample XRF-26 from the Northport RI (Ecology 2019) was not included in this evaluation because bioavailability parameters were not measured. The clay content of Hanford soils was not reported; rather, a combined measure of clay and silt was reported. Accordingly, the combined measures of clay and silt in both the Hanford and UCR soils were evaluated. Overall, there is some parameter overlap between the Hanford and UCR soils, but the UCR soils are more variable (Figure 1).

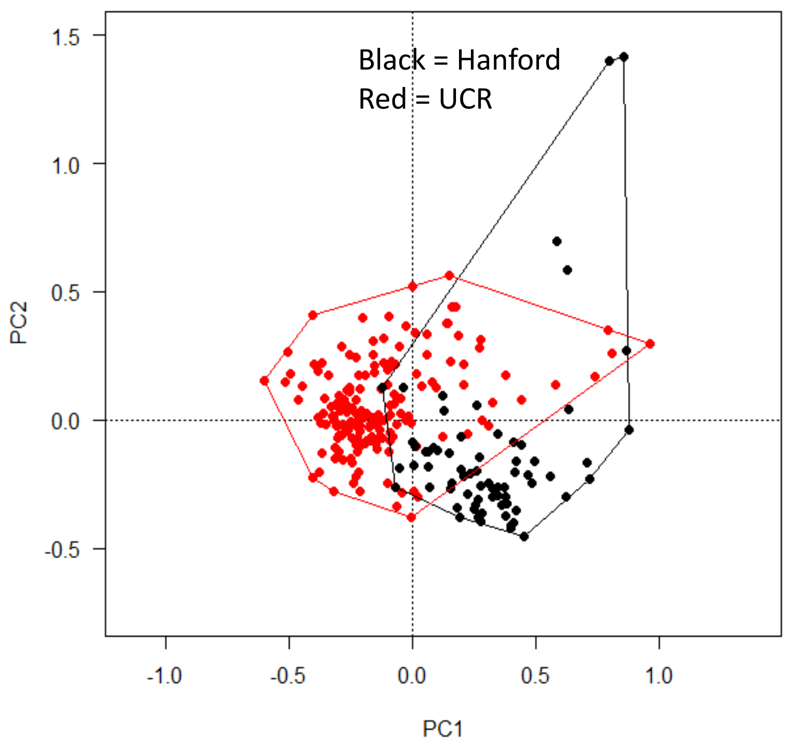


Figure 1. Principal component analysis of properties (CEC, TOC, pH, and %clay/silt) of Hanford and UCR soils

The PCA indicated differences between the Hanford and UCR soils regarding properties that influence metal bioavailability. Therefore, the Threshold Calculator was used to calculate and compare bioavailability-adjusted benchmarks for Hanford and RFDA and WSDA soils to assess the relative bioavailability conditions. The comparison was conducted using lead (plants) and zinc (plants and invertebrates) as examples, as these are two of the metals of interest in UCR soils.[7]

The bioavailability-adjusted lead benchmark for plants and the bioavailability-adjusted zinc benchmark for invertebrates are based on eCEC, and the zinc bioavailability-adjusted benchmark for plants is based on both eCEC and pH. As for RFDA and WSDA soils, CEC was reported for Hanford soils, and the eCEC was calculated as shown in Equation 2 of this memorandum.

As noted, the combined clay and silt content of Hanford soils was reported but not the clay-only content. Accordingly, the eCEC for the Hanford soils was calculated assuming that clay composed both 25 and 75% of the clay/silt fraction. Thus, bioavailability-adjusted benchmarks were calculated based on a higher bioavailability assumption (25% clay in the clay/silt fraction) and a lower bioavailability assumption (75% clay in the clay/silt fraction) and compared to bioavailability-adjusted benchmarks for RFDA and WSDA soils and Hanford PRGs. If bioavailability-adjusted benchmarks for RFDA and WSDA soils are similar to or greater than those for Hanford soils, then metals in Hanford soils would be expected to have similar or greater bioavailability as RFDA and WSDA soils. Therefore, the Hanford PRGs would be useful for interpreting Eco-SSLs/SSLs and bioavailability-adjusted benchmarks for RFDA and WSDA soils.

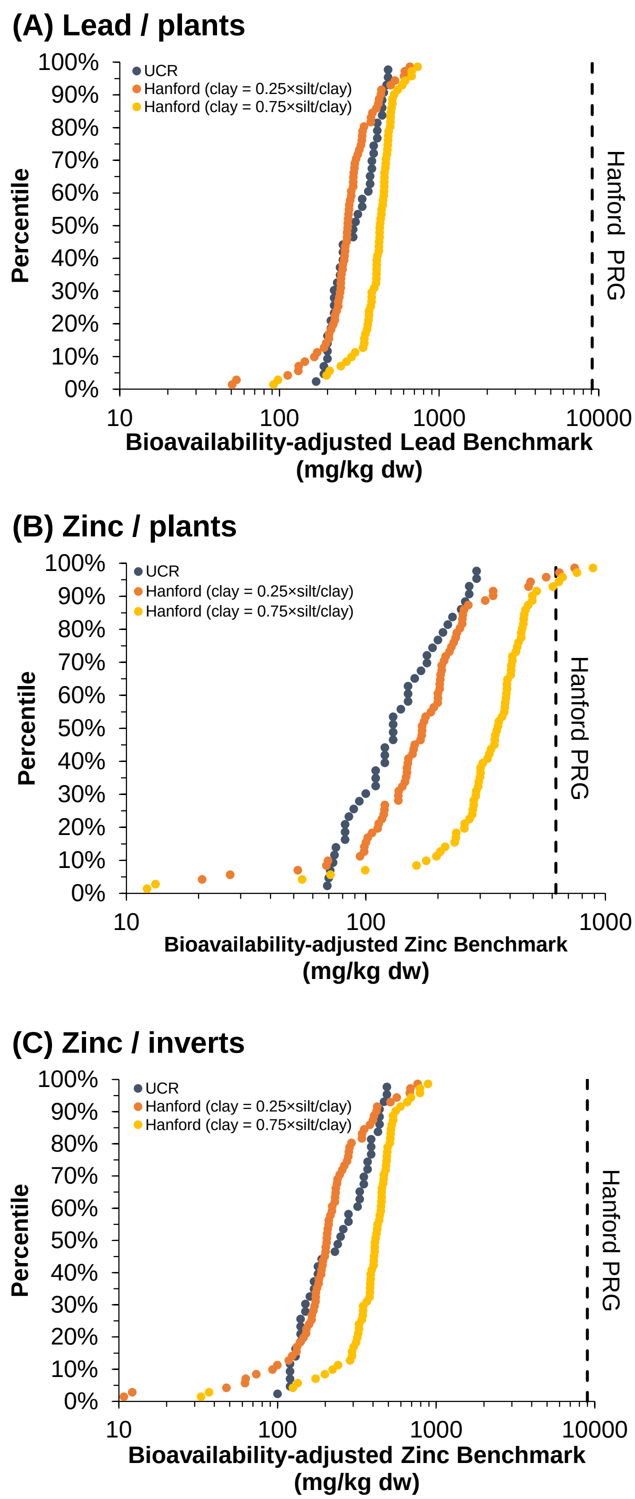
The bioavailability-adjusted lead benchmarks for plants for RFDA and WSDA soils were generally within the range of benchmarks for Hanford soils based on the assumptions of 25% or 75% clay in the silt/clay fraction (Figure 2A). This pattern suggests that the lead bioavailability in Hanford soils is comparable to that in RFDA and WSDA soils. Given the comparability in lead bioavailability conditions and that the bioavailability-adjusted lead benchmarks are more than an order of magnitude less than the Hanford lead PRG, this likewise indicates that bioavailability-adjusted benchmarks for lead in the RFDA and WSDA soils are conservative.

For zinc and plants, the bioavailability-adjusted benchmarks for the RFDA and WSDA soils were generally less than those for Hanford soils, even for the more conservative 25% clay assumption for Hanford soils (Figure 2B). This pattern, which is different than that observed for lead and plants, is attributable to soil pH, which affects the bioavailability-adjusted benchmark for zinc but not for lead. On average, the pH of RFDA and WSDA soils is 5.8 and the pH of Hanford soils is 7.1, corrected for 0.01 M $CaCl_2$ solution, per Oorts (2020). The lower pH in RFDA and WSDA soils favors higher zinc bioavailability to plants (compared to Hanford soils), but the influence of eCEC is also important. The Hanford PRG of 621 mg/kg dw, is less than the bioavailability-adjusted benchmarks for Hanford soils in less than 10% of the samples (Figure 2B), but this does not necessarily suggest that the bioavailability-based benchmarks in those cases are less protective than the PRG because the PRG is an unbounded NOEC.

[7] The copper PRG for Hanford was not based on site-specific bioassays, so it was not included in this evaluation.

Accordingly, it is assumed that the bioavailability-based benchmarks for UCR soils would provide the same level of protection relative to the Hanford PRG by accounting for differences in bioavailability conditions.

The pattern in bioavailability-adjusted benchmarks for zinc and invertebrates was similar to that of lead and plants, with benchmarks for RFDA and WSDA soils generally within the range of benchmarks for Hanford soils based on the assumptions of 25% or 75% clay in the silt/clay fraction (Figure 2C). This pattern suggests that the zinc bioavailability in Hanford soils is comparable to that in RFDA and WSDA soils. As for lead and plants, given that the bioavailability-adjusted zinc benchmarks for invertebrates are an order of magnitude less than the Hanford zinc PRG, this likewise indicates that bioavailability-adjusted benchmarks for zinc in RFDA and WSDA soils are conservative.



Note: Soil samples collected from the RFDAs and WSDAs (excluding sample location XRF-26 due to a lack of pH and organic carbon measurements)

Figure 2. Comparison of bioavailability-adjusted benchmarks for Hanford and UCR soils for (A) lead and plants, (B) zinc and plants, and (C) zinc and invertebrates

This evaluation indicates that bioavailability-based benchmarks for Hanford soils are almost always less than unbounded NOEC-based Hanford PRGs for lead (plants) and zinc (plants, invertebrates), and sometimes less by an order of magnitude. This indicates that the bioavailability-based benchmarks for Hanford soils provide a level of protection that is similar to or greater than the level of protection associated with the approved PRGs for Hanford soils. The RFDA and WSDA soils have bioavailability conditions for lead (plants) and zinc (invertebrates) that are comparable to Hanford soils, and generally greater bioavailability conditions for zinc (plants). Differences in bioavailability, when they occur are accounted for in the bioavailability-based benchmarks, so conclusions on the protectiveness of the bioavailability-based benchmarks for Hanford soils relative to unbounded NOEC-based PRGs is assumed to likewise apply to RFDA and WSDA soils.

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