TECHNICAL MEMORANDUM

Development of Human Health Risk-Based Preliminary Remediation Goals for Operable Unit 5

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This technical memorandum presents the approach, assumptions, and outcome from developing human health risk-based preliminary remediation goals (PRGs) for Operable Unit 5 (OU5) of the Tar Creek Superfund Site in Ottawa County, Oklahoma. This technical memorandum also summarizes the ecological PRGs developed using the detailed ecological risk assessment (DERA) as they also are considered as part of the final remedial goal selection process. The preferred PRGs for the final human health risk assessment (HHRA) chemicals of concern (COCs) were identified, and the final remedial goals are discussed in the conclusions.

1.0 Site Background

The Tar Creek Superfund Site is located within the Tri-state Mining District (TSMD), a historical lead and zinc mining area that includes portions of southeast Kansas, southwest Missouri, and northeast Oklahoma (Figure 1). Historical mining activities in the TSMD resulted in contamination of soil, surface water, groundwater, and sediments in the Neosho River and Spring River basins by cadmium, lead, zinc, and other heavy metals.

Generally, OU5 is defined by EPA Region 6 as sediments and surface water in perennially flowing creeks, streams, and rivers that may be impacted by historical mining activities within the Oklahoma portion of the TSMD and upstream portions in Kansas and Missouri. The potential exposures addressed under OU5 are associated with the aquatic environment. The definition of OU5 has been further refined by EPA Regions 6 and 7 for the purposes of conducting the remedial investigation and HHRA to include the following seven specific watersheds that flow downstream from EPA Region 7 states (Kansas and Missouri) into EPA Region 6 (Oklahoma):

- Fourmile Creek (upstream background or reference location unaffected by historical mining activities)
- Elm Creek
- Tar Creek (including Lytle Creek)
- Neosho River
- Beaver Creek
- Lost Creek
- Lower Spring River (the portion of Spring River downstream of Empire Lake in Kansas)

2.0 Remedial Action Objectives

Remedial action objectives (RAOs) are medium-specific or operable unit-specific goals for protecting human health and the environment (EPA, 1988). Remedial actions must protect public health and the environment and address potential risks identified in the human health and ecological risk assessments. Once RAOs are designated, they serve as a basis for developing remedial action alternatives necessary to meet remedial goals. In general, remedial goals are media- and chemical-specific concentrations that pose no unacceptable risk to human health and the environment (or background levels if the risk-based levels are below background). For OU5, RAOs have been developed for the media of concern that have potentially unacceptable risks to human health and the environment based on the findings of the HHRA (CH2M, 2020a) and the advanced screening level ecological risk assessment (SLERA) (MacDonald Environmental Sciences, Limited [MESL], 2010). The media of concern for the site are sediment, surface water, and biota.[1]

The following preliminary human health RAOs were identified in the remedial investigation report (CH2M, 2020b) based on the anticipated outcome of the HHRA at that time:

- Minimize or prevent human exposures from direct or indirect contact with elevated metals in OU5 sediment and surface water[2] that may pose an unacceptable risk
- Minimize or prevent human exposures to elevated metals found in OU5 aquatic biota that may pose an unacceptable risk

In addition, the advanced SLERA (MESL, 2010) identified preliminary RAOs for sediment and pore water that address potential risks to aquatic receptors, aquatic-dependent wildlife, and humans associated with exposure to contaminated sediments. These preliminary RAOs related to aquatic receptors and aquatic-dependent wildlife include:

- RAO for aquatic receptors: Minimize or prevent exposure to sediments and/or pore water that are sufficiently contaminated to pose moderate or high risks, respectively, to microbial, aquatic plant, benthic invertebrate, or fish communities (particularly for fish species that use sediment substrates for spawning)
- RAO for aquatic-dependent wildlife: Minimize risks to sediment-probing birds or omnivorous mammals associated with incidental ingestion of sediments during feeding activities

3.0 Overview of the Basis for Preliminary Remediation Goals

To meet the RAOs, human health and ecological PRGs typically are developed for use in the feasibility study to define the extent of contaminated media requiring remedial action. In general, PRGs establish media-specific concentrations of COCs that will pose no unacceptable risk to human health and the environment. Section 4 summarizes the ecological PRGs developed using the DERA (CH2M, 2020c), Section 5 summarizes the HHRA (CH2M, 2020a), and Section 6 presents the approach used to develop the human health PRGs described herein. The human health and ecological PRGs were developed considering the following:

- Risk-based concentrations associated with a noncancer hazard index (HI) of 1, a 5% probability of exceeding a target blood lead level (BLL) (5, 8 and 10 micrograms per deciliter [µg/dL])
- Site-specific toxicity thresholds (SSTTs) corresponding to 10% (T10) or 20% (T20) reduction in survival or biomass compared to various reference envelope limits and/or multi-metal risk-based concentration (RBC) Σ PEC-$Q_{Cd,Pb,Zn}$ indicating a significant ecological risk.

[1] Surface water and biota impacts are due to sediment concentrations; therefore, RAOs are established for sediments.

[2] Potential exposure to mine discharge also was evaluated based on the same exposure assumptions used for surface water.

- Contaminant-specific applicable or relevant and appropriate requirements (ARARs); however, no sediment ARARs are available. Although ARARs in surface water are present, the additional analysis of surface water ARARs will be conducted in the feasibility study. Therefore, no ARAR-based PRGs were identified in this technical memorandum.
- Background concentrations.

4.0 Summary of Ecological Preliminary Remediation Goals

The DERA (CH2M, 2020c) did not explicitly identify RBCs for surface water, pore water, or sediment. However, SSTTs used in the DERA can be used as RBCs to support PRG development. SSTTs were defined for:

- Surface water
- Sediment
- Pore water
- Invertebrate tissue
- Freshwater mussel species richness

The DERA focused on evaluating risks to the benthic invertebrate community posed by exposure to contaminated environmental media in the study area; sediment chemistry was used as a primary line-of-evidence for evaluating and summarizing risks to the benthic community. As such, risk associated with direct contact and toxicity of sediments to benthic invertebrates is the primary risk driver for OU5, and RBCs associated with low and moderate risk may serve as the basis for PRG selection.

The concentration of each chemical of potential concern (COPC) or COPC mixture that corresponded to a 10% reduction in survival or biomass compared to various reference envelope limits is defined as the "T10" value. Selection of a T10 SSTT as an RBC provides significant risk reduction. Using this RBC, the incidence of toxicity would be reduced from approximately 80% to less than 10%. The T10 SSTT as an RBC could serve as a reasonable basis for identifying a PRG that addresses the RAO for aquatic receptors. The RBCs based on the T10 for the single metals of cadmium, lead, and zinc as well as the multi-metal RBC Σ PEC-$Q_{Cd,Pb,Zn}$ are as follows:

- Cadmium – 11.1 milligrams per kilogram of dry weight sediment (mg/kg dw)
- Lead – 150 mg/kg dw
- Zinc – 2,083 mg/kg dw
- $\sum$ PEC-$Q_{Cd,Pb,Zn}$ - <6.47

5.0 Summary of Human Health Risk Assessment

The HHRA (CH2M, 2020a) was conducted to evaluate the potential risks associated with exposures to COPCs by human receptors identified in the OU5 study area under current and reasonably foreseeable future land use conditions. The HHRA was conducted consistent with EPA *Risk Assessment Guidance for Superfund* (EPA, 1989) and other supplemental EPA guidance documents (EPA, 1995, 2001, 2003a, 2004, 2009, 2010, 2011, 2014). In addition, input from stakeholders was considered in developing the conceptual exposure model and exposure assumptions for characterizing exposures to tribal members and citizens and the general public. EPA's Technical Review Workgroup (TRW) for Metals and Asbestos Lead Committee also was consulted regarding the approach for lead evaluation for the OU5 study area.

The HHRA evaluated potential exposures to sediment, surface water, mine discharge, and aquatic biota at the site, and estimated potential risk for the following receptors:

- Tribal Lifeway (TLW) (adults and children)
- Aquatic Workers (adults only) (for example, hatchery or environmental employees)
- General Public (GP) (adults and children)

Table 1 summarizes the exposure scenarios evaluated for each receptor.

Using the data groupings identified for each watershed and exposure medium, potential exposures to COPCs were quantified based on exposure factors developed using EPA guidance documents, literature describing exposure characteristics of tribal members and citizens, and inputs from the Quapaw Nation and Tar Creek Trustee Council Indian Tribes. For metals other than lead, the Comprehensive Environmental Response, Compensation, and Liability Act specifies an acceptable site excess lifetime cancer risk (ELCR) range of one in a million to one in ten thousand (1×10^{-6} to 1×10^{-4}). Generally, remedial actions are not warranted for site media with an ELCR of 1×10^{-4} or a HI of 1 or less, although it may be warranted if other site-specific information suggests to risk managers that action is appropriate.

Based on the risk estimates, preliminary COCs were identified. The preliminary COCs are identified for a receptor scenario when the potential ELCR or HI exceeds EPA threshold values (a cumulative ELCR of 1×10^{-4} or a target-organ-specific HI of 1), except for lead. When a target ELCR of 1×10^{-4} is exceeded for an exposure medium for the receptor scenario, the COPCs posing an individual ELCR greater than 1×10^{-6} in the environmental medium were identified as preliminary COCs. When a target-organ-specific HI of 1 is exceeded for an exposure medium for the receptor group, the COPCs posing a hazard quotient greater than 0.1 for that target organ in the environmental medium responsible for the unacceptable HI are identified as preliminary COCs.

In addition, potential exposure to lead in environmental media within the OU5 study area was evaluated separately because the approach for the evaluation of lead (using biokinetic modeling) is different from other COPCs. The purpose of the lead analysis included in the HHRA was to identify potential unacceptable risk associated with exposure to lead in environmental media within the OU5 study area. Given the elevated concentrations of lead detected in OU5 media (for example, the average lead concentration in Elm Creek sediment is as high as 4,281 milligrams per kilogram [mg/kg]) and the limitations of the available lead models, a conscious effort was made to streamline the evaluation of potential lead exposures in the OU5 study area media without expending considerable effort in identifying representative central tendency exposure parameter values characterizing the unique OU5 study area exposure scenarios. Potential lead exposure was evaluated using the Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children, Windows Version 1.1, Build 11 (EPA, 2010) and the Adult Lead Methodology (ALM) (EPA, 2017).

Based on the risk estimates and output from the lead models, preliminary COCs were identified. Preliminary COCs are chemicals that drive risks based on the exceedance of an EPA-acceptable ELCR and/or HI and the lead model output (using a target BLL of 5 µg/dL), without regard for background levels or relation to sources associated with historical site activities. The list of preliminary COCs was refined using two additional considerations to identify final COCs: (1) background comparisons, and (2) attribution to mine-related contamination. Final COCs are listed in Table 2.

6.0 Human Health Risk-Based PRG Development Approach

To support the remedial alternative selection process, PRGs were developed for the final COCs identified in the HHRA. In general, the PRGs can be based on either (1) ARARs or (2) RBCs associated with specified target risk levels. No sediment ARARs are available. Although ARARs in surface water are present, the additional analysis of surface water ARARs will be conducted in the feasibility study; therefore, no ARAR-based PRGs were identified in this technical memorandum.

The objective of the PRG development is to develop sediment PRGs protective of human health, not only for direct sediment contact but also secondary exposure through direct contact of surface water and food consumption. Based on the historical site activities and findings of the previous investigations, lead, cadmium, and zinc are the primary chemicals of interest. Also, these are the only chemicals identified as the final COCs in sediment. Therefore, PRG development focuses on sediment PRGs for

these three COCs. Because the approach used in the exposure analysis of lead is different from that of the cadmium and zinc hazard assessment, PRGs are discussed separately in the sections below.

6.1 PRG Development Approach for Lead

The development of a potential PRG for lead in sediment considers a wider range of potential exposure assumptions to provide risk managers with a range of potential outcomes for decision-making. Although lead was identified as a sediment COC for adult receptors (such as Aquatic Workers), lead PRGs were developed for child receptors using the IEUBK model only because children are a more sensitive receptor group for lead exposure than adults and also because of the extended capability of the IEUBK model as a multi-media exposure model over the ALM model, whose functionality is limited primarily to exposure through the ingestion route.

Before preparing this technical memorandum, multiple sets of lead PRGs in sediment were calculated for the GP and TLW children using input parameter values reflecting various exposure characterization and IEUBK modeling approaches. These lead PRG development approaches have been discussed with the EPA Region 6 remedial project manager for OU5 and EPA Region 6 and Region 7 risk assessors during a series of technical meetings and has been reviewed by the EPA TRW Lead Committee. This technical memorandum summarizes the select sets of sediment PRGs that were calculated based on the approaches that were discussed during the meetings and that have incorporated review comments received by the TRW (Appendix A, Attachment 1). Details regarding PRG development approaches and the range of PRGs under various exposure assumptions are presented in Appendix A. Based on comments received on the lead PRG development approach from the EPA TRW, five sets of PRGs are presented in this technical memorandum. All the IEUBK model runs used target BLLs of 5, 8, and 10 µg/dL, consistent with the lead exposure analyses in the HHRA (CH2M, 2020a). The five sets of PRGs are described below and presented in Table 3.

6.1.1 High-End PRGs and Refined High-End PRGs Using Time-Weighted Average (TWA) Approach

The first two sets of PRGs were developed based on the general (streamlined) approach and high-end exposure assumptions used in the lead exposure analysis in the HHRA (CH2M, 2020a). In these sets of PRGs, sediment exposure is treated as soil exposure, and surface water exposure is treated as drinking water in the model (i.e., assumed daily exposure to OU5 sediment and surface water without considering receptors' exposure frequency at OU5) and the calculated soil PRGs are presented as sediment PRGs.

General Public

- High-End Exposure Scenario – Sediment PRGs are based on the IEUBK default values and the site-specific exposure point concentration for surface water; this is considered to be the high-end of the potential PRG range for the GP child and reflects the scenario evaluated in the HHRA[3].
- Refined High-End Exposure Scenario Using TWA Approach – Refined PRGs were developed assuming total lead exposure from OU5 exposure media plus non-OU5-related sources (for example, exposure to lead in residential yard soil), but used a TWA approach[4]. The TWA approach was used to account for lead exposure in two exposure areas (exposure at OU5, and exposure at their residence) using the assumed frequency of OU5 visits and additional lead exposure to soil at their residential yards. A GP child is assumed to visit OU5 once a week and spend the rest of the week at their residence.

Tribal Lifeway

- High-End Exposure Scenario – Sediment PRGs are based on the tribal reasonable maximum exposure (RME) parameter values (sediment ingestion rate of 400 milligrams per day [mg/day]) and is considered the high-end of the PRG range for the TLW child, reflecting the scenario evaluated in the

[3] This set of lead PRGs corresponds to the high-end PRGs (Scenario 1 in Table 4 of Appendix A).

[4] This set of lead PRGs correspond to the high-end TWA PRGs (Set 2a in Table 5 of Appendix A).

HHRA[5]. Please note that the scenario using the RME sediment ingestion rate of 400 mg/day is included in the PRG development solely to reflect the scenario evaluated in the HHRA. The TRW Lead Committee does not consider 400 mg/day to be a central tendency soil-dust ingestion rate for a human child receptor and considers the Harper (2007) report used as the basis of the ingestion rate to be outdated (TRW review comments are included in Appendix A, Attachment 1).

- Refined High-End Exposure Scenario Using TWA Approach – As done for the GP, refined PRGs were developed assuming total lead exposure from OU5 exposure media plus non-OU5-related sources[6]. A TLW child is assumed to visit OU5 5 days a week and spend the rest of the week at their residence.

6.1.2 Hybrid Exposure Scenario Incorporating Exposure Characteristics of Two Child Age Groups

Based on the recommendations from the TRW, hybrid PRGs were calculated for the TLW child only using the hybrid approach based on assumed exposure scenarios distinctive for two child age groups[7]. Like the refined high-end PRGs using the TWA approach above, lead intake through sediment/soil and water in two exposure areas (exposure at OU5 and residential yards) is estimated using the TWA approach. However, under this set of PRGs, OU5 medium-related exposures are addressed only for the older child age group that is most likely to visit OU5 and engage in the expected TLW activities, while the PRGs also incorporated the younger children's exposure to residential yard soil and drinking water.

The input parameter values for the IEUBK model and results of each set of IEUBK model runs are summarized in Table 3 and graphically presented on Figure 2.

6.2 PRG Development Approach for Cadmium and Zinc

Sediment PRG for Direct Contact Exposure Pathway

Cadmium and zinc were identified as final COCs in sediment for the direct contact pathway (incidental ingestion and dermal contact) under two exposure scenarios:

- TLW Receptors (cadmium and zinc)
- Aquatic Workers (cadmium only because zinc was not a COC for aquatic workers)

No sediment COCs were identified for GP receptor scenarios; therefore, PRGs were not calculated for the GP receptor.

Risk-based PRGs for the direct contact exposure pathway were calculated based on the site-specific RME assumptions and toxicity values used in the HHRA (Tables 4.1 [exposure assumptions] and 5.1 [toxicity values] of Appendix B of the HHRA [CH2M, 2020a]). Because child receptors are assumed to have a higher COC intake than adult receptors, the PRGs for the TLW receptor scenario were calculated using the child receptor exposure assumptions. Because cadmium and zinc do not share the same target organ, the target HI is set at 1 for each COC. PRGs are calculated based on the general equations below:

$$PRG = \frac{RfD}{Intake} \times HI \ (1)$$

Where:

RfD = reference dose (mg/kg$_{BW}$ per day)
Intake = calculated based on RME assumptions (mg/kg$_{BW}$ per day)
HI = target hazard index of 1 (unitless)

[5] This set of lead PRGs correspond to the high-end PRGs (Scenario 5 in Table 4 of Appendix A).

[6] This set of lead PRGs correspond to the high-end TWA PRGs (Set 2a in Table 5 of Appendix A).

[7] These sets of lead PRGs correspond to the hybrid PRGs (Set 2b in Table 5 of Appendix A).

As indicated in the equation below, the PRGs for each exposure route (ingestion and dermal contact) were calculated first. Then, the overall PRGs for the direct contact exposure pathway were calculated as an inverse sum of the reciprocals of PRGs for each exposure route.

The PRGs for the direct contact exposure pathway were calculated using the following equation:

$$Sediment\ PRG_{DC}\left(\frac{mg}{kg_{sed}}\right)=\frac{1}{\left(\frac{1}{PRG_{ing}}+\frac{1}{PRG_{derm}}\right)}$$

Where:

Sediment PRG_{DC} = sediment PRG for direct contact pathway (mg/kg of sediment)
Sediment PRG_{ing} = sediment PRG for ingestion route (mg/kg of sediment)
Sediment PRG_{derm} = sediment PRG for dermal contact pathway (cadmium only) (mg/kg of sediment)

Note that PRGs in the equations above are presented in units of milligrams of COCs per kilogram of sediment (dry weight). Specific exposure factor values and toxicity values used in the calculations are summarized in Table 4.

6.2.1 Aquatic Plant PRGs for Food Consumption Pathway

Similar to the approach used to develop the PRGs for the direct contact exposure pathway, PRGs were calculated for the aquatic plant consumption pathway (Table 4). Although four additional COCs (barium, copper, nickel, and silver) were identified in various OU5 food items for the biota consumption pathway under the TLW exposure scenario, the development of PRGs focuses on cadmium and zinc in aquatic plants only, because cadmium and zinc in aquatic plants constitute more than 92% of the total hazard associated with COC exposure through consumption of OU5 food items. Aquatic plant PRGs were calculated based on two fraction ingested values (assuming either 25% or 100% of ingested aquatic plants originating from OU5).

The relationship between COC concentrations in sediment and aquatic plants is estimated using the regression equations empirically developed based on site-specific collocated sediment and aquatic plant data (arrowhead root); refer to the sediment and aquatic plant analysis presented in Appendix B. The following equations were developed:

Cadmium: $Aquatic\ Plant\ Conc. = Sediment\ Conc. \times Slope\ (0.136) + Intercept\ (-1.64)$

Zinc: $Aquatic\ Plant\ Conc. = Sediment\ Conc. \times Slope\ (0.120) + Intercept\ (-194.3)$

6.2.2 Sediment PRG for Combined Direct Contact and Food Consumption Exposure Pathways

The sediment PRGs addressing combined exposure from the direct contact exposure pathway (incidental ingestion and dermal contact) and aquatic plant consumption pathway can be expressed in the following general equation:

$$Sediment\ PRG_{DC-AP}\left(\frac{mg}{kg_{sed}}\right)=\frac{1}{\left(\frac{1}{PRG_{DC}}+\frac{1}{PRG_{AP-Sed}}\right)}$$

$PRG_{AP\text{-}sed}$ is the estimated risk-based COC concentration in sediment that would be protective of the aquatic plant consumption pathway. $PRG_{AP\text{-}sed}$ is the reciprocal of the ratio for a unit increase of hazard per a unit increase of COCs in sediment. Please note however, that the relationship between aquatic plant and sediment is not explained as this simple ratio, but instead the relationship described by the regression equations above. The actual equations used in the calculations of $PRG_{DC\text{-}AP}$ are presented in Table 4. The calculated PRGs under various scenarios are presented in Table 5 and Figure 3.

7.0 Uncertainties

As indicated in Section 6.6 of the HHRA, the methodologies, assumptions, and toxicity information used in the PRG development share the same uncertainties identified in the HHRA. Three of the major sources of the uncertainties are the limitation of the biokinetic model (IEUBK model) used for the lead PRGs, the development of a lead PRG using the high-end exposure assumptions, and protectiveness of the calculated sediment PRGs to address secondary exposure through surface water and biota consumptions.

In addition to the inherent uncertainty associated with RME exposure values identified for the TLW exposure scenario, the use of the upper-end exposure parameter values (such as RME values) in the IEUBK model also introduces a significant uncertainty, since the model is designed to predict the cumulative distribution of BLLs based on central tendency exposure parameter values. Furthermore, there are also uncertainties associated with applying the IEBUK model to the evaluation of the unique OU5 exposure scenarios. For instance, the model was designed to predict BLL to mainly address continuous lead exposure for the GP under a residential exposure setting, which differs in the target population and exposure characterization at OU5. The OU5 exposure can be characterized as intermittent exposure to sediment or surface water occurring for a part of the day or week, at a location separate from residences by a specific subpopulation (such as TLW receptors). The intermittent exposure to lead in OU5 media was addressed using the TWA approach, which follows the EPA guidance document, "Assessing Intermittent or Variable Exposures at Lead Sites" (2003b) and is considered an appropriate approach for the assessment of lead when exposures are not continuous.

Among the various input variables, sediment ingestion rate is the most influential parameter variable on the lead sediment PRG (the sensitivity analysis of various key parameter values is presented in Appendix A, Attachment 2). As indicated in the paragraph above, there is a large degree of uncertainty associated with the use of upper-end exposure values (such as a sediment ingestion rate of 400 mg/day) as a central tendency estimate in the IEUBK model. The TRW Lead Committee made the following recommendation regarding the sediment ingestion rate of 400 mg/day used in the lead exposure analysis (CH2M, 2020a): *"…the selected ingestion rate of 400 mg/day for sediment seems very high compared to what is typically used for children (generally 100 mg/day or less). Central tendency estimates are recommended for lead risk assessment."* Furthermore, the TRW commented that, *"Because of the way the EPA Lead models use statistical parameters to calculate an upper bound exposure, BLL, and PRG, central tendency values should be used for inputs in the IEUBK and Adult Lead Methodology (ALM). The TRW Lead Committee does not consider 400 mg/day to be a central tendency soil-dust ingestion rate (IR) for a human child receptor."*

The committee also provided a comment indicating that soil ingestion rates of 400 mg/day cited from the Harper (2008) report and originally presented in Harper et al. (2007) as the basis of sediment ingestion rate are outdated (TRW review comments are included in Appendix A, Attachment 1). The TRW further commented that the 400 mg/day for soil (not dust) relies in large part on EPA's 1997 Exposure Factors Handbook (EFH) Table 4-23, upper percentile (defined as 95th percentile, not undefined as suggested by Harper on p. 259 of the 2007 report). However, the 1997 EFH footnoted the 400 mg/day for soil with, *"Study period was short; therefore, these values are not estimates of usual intake."* Irvine et al. (2014) reported a 95th percentile ingestion rate of 361 mg/day for soil ingestion rate but stated, *"… the mean as well as the 95th percentile estimates [determined by Irvine et al.] lower than Harper et al.'s (2007) prediction of soil ingestion rates for First Nations people (i.e., 400 mg/day)."* Harper et al. (2007) did not actually provide a prediction of a 400 mg/day ingestion rate for soil, but rather relied in large part on the EPA's 1997 EFH Table 4-23 upper percentile.

It should be noted that the approach of sediment PRG development established with EPA Region 6 is considered highly conservative because sediment samples were collected from perennially flowing creeks, streams, and rivers and are sediment attached to skin surface, which is expected to be readily

washed off when receptors are out of water. Some of the EPA regions have an established policy of not evaluating exposure to sediment perennially covered with water for this reason. For instance, EPA Region 4 (2018) has long followed a policy of only quantifying human exposure to sediment that is not covered by water (for example, sediment in an intermittent stream for the portion of the year the stream is without water) and generally considers it unnecessary to evaluate human exposure to sediments that are always covered by surface water, while EPA Region 1 evaluates only sediments and water to about knee depth. Additionally, all the scenarios included in the lead PRG development assume that track-in of OU5 sediment into a residence occurs and that there is additional sediment exposure through indoor dust ingestion at the residence. Although some level of sediment track-in into the home may occur, the degree of it is expected to be limited for the reasons discussed above. The PRGs estimated based on an assumption of no sediment track-in are higher than the lead sediment PRGs presented in Table 3. For instance, the lead PRG assuming no sediment track-in is 638 mg/kg (not presented in tables) based on a target BLL of 5 µg/dL, which is noticeably higher than the 414 mg/kg calculated assuming that there is sediment track-in (presented in Table 3).

Additionally, there is a large degree of uncertainty associated with the assumption used to predict the media transfer of COCs (for example, COC transfer from sediment to surface water or biota). After sediment remediation, it might take some time for the concentrations of COCs in surface water and biota to reach equilibrium with, and reflect the reduced concentrations in, the remediated sediment. However, remediation of sediment to the ecological PRGs is expected to result in sufficient reduction of COC concentrations in surface water and biota to meet acceptable human health and ecological risk and hazard levels. The efficacy of sediment remediation will be assessed in the future monitoring and periodic review process.

8.0 Conclusions

Human health risk-based PRGs have been calculated for the final sediment COCs (lead, cadmium, and zinc) identified in the HHRA (CH2M, 2020a). The objective of the work described by this technical memorandum was to identify sediment PRGs protective of the primary direct contact exposure to sediment as well as the secondary exposure through direct contact with surface water and food consumption. These human health risk-based PRGs are provided to EPA risk managers for their use in selecting the final remedial goals for the site, in consideration also of the ecological PRGs. Because the approach used in the human health exposure analysis of lead is different from that of the cadmium and zinc hazard assessment, PRGs are calculated separately for lead (Table 3) using EPA's biokinetic model (IEUBK model). Cadmium and zinc PRGs (Table 5) were calculated using the toxicity values and RME assumptions used in the HHRA and empirically established regression equations between sediment and aquatic plants.

Among the various input variables tested for sensitivity to the resulting lead PRG in sediment (Appendix A, Attachment 2), the sediment ingestion rate is the most influential parameter variable on the resulting sediment PRG. All scenarios using a sediment ingestion rate of 400 mg/day yield a PRG lower than the lead background threshold value (BTV) of 59 mg/kg based on a target BLL of 5 µg/dL. For the scenarios using a sediment ingestion rate of 400 mg/day, a reduced soil/dust absorption fraction (e.g., 20%), or a TWA approach accounting for a fraction of exposure at OU5, the sediment PRG does not noticeably increase above the BTV (refined high-end PRG using TWA approach as presented in Table 3). One of the TRW Lead Committee's recommendations indicates that the PRGs established using the hybrid scenario (hybrid PRGs as presented in Table 3) is the best option since it considers all sources of exposure, while at the same time uses a lower soil ingestion rate and TWA strategy to address both OU5 sediment and residential soil exposure. Note that sediment PRGs established using this hybrid approach are above the lead BTV of 59 mg/kg and reflect risk using appropriate exposure assumptions. Based on the TRW Committee's recommendation, the PRGs established using the hybrid scenario are considered the preferred lead PRGs.

The preferred lead PRG based on a target BLL of 5 µg/dL[8] and the cadmium and zinc PRGs calculated for direct contact and aquatic food consumption pathways are all estimated to be greater than the ecological PRGs for T10 (SSTT corresponding to 10% reduction in survival or biomass). In other words, the ecological-based PRGs are more stringent than the human health-based PRGs. Therefore, if attainment of the ecological PRGs for T10 (more stringent PRGs than human health risk-based PRGs) are identified as an RAO, the final remedial goals will be established based on the ecological PRGs.

9.0 References

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Tables

Table 1. Summary of Exposure Scenarios Evaluated in the HHRA

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Exposure Medium	Exposure Scenario/Receptor Population	
	Tribal Lifeway	**General Public**
Sediment	Hunting/fishing/gathering and recreational activities • Incidental ingestion • Dermal contact	Recreational activities • Incidental ingestion • Dermal contact
Surface Water	Hunting/fishing/gathering and recreational activities • Incidental ingestion • Dermal contact Potable source • Ingestion • Dermal contact Sweat lodge use • Ingestion • Dermal contact • Inhalation (water vapor)	Recreational activities • Ingestion • Dermal contact Potable source • Ingestion • Dermal contact
Mine Discharge	Hunting/fishing/gathering and recreational activities • Dermal contact	Recreational activities • Dermal contact
Fish Tissue (Estimated whole fish concentrations)	• Food consumption	
Fish Tissue (Game Fish Fillet)		Recreational Fishing • Food consumption
Shellfish Tissue (Mussel and Asian Clam)	• Food consumption	
Aquatic Plant as Food (Arrowhead and Duckweed)	• Food consumption	
Aquatic Plant as Salve (Arrowhead)	• Dermal contact (medicinal use)	
Amphibian/Aquatic Reptile Tissue (Frog Legs)	• Food consumption	
Semi-Aquatic Mammal Tissue (Raccoon)	• Food consumption	

Notes:

This table presents exposure scenarios/pathways for child receptors only.

HHRA = human health risk assessment

Table 2. Final COCs for Tar Creek OU5

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Final COCs	Sitewide (Biota Only)	Elm Creek	Tar Creek	Neosho River	Beaver Creek	Lost Creek	Lower Spring River
Sediment							
Cadmium		TL	TL, AW		TL		
Lead		TL, AW, GP	TL, AW, GP		TL, GP		TL, GP
Zinc		TL	TL		TL		
Surface Water							
Antimony		TL					
Arsenic			TL, AW, GP				
Barium				TL			
Cadmium		TL, AW, GP	TL, GP		TL		
Cobalt			TL, AW, GP		TL		
Iron			TL, GP	TL			
Lead[a]		TL, GP	TL, GP		TL, GP		
Manganese			TL, AW, GP				
Nickel		TL	TL, AW		TL		
Zinc		TL	TL				
Biota[b]							
Barium	TL						
Cadmium	TL						
Copper	TL						
Lead	TL, GP						
Nickel	TL						
Silver	TL						
Zinc	TL						

Notes:

[a] Lead in surface water was not evaluated for Aquatic Workers because of the limitations of the ALM.

[b] Final COCs were identified based on sitewide dataset.

Final COCs are identified for the following receptors: TL = Tribal Lifeway, AW = Aquatic Worker, GP = General Public.

ALM = Adult Lead Methodology

COC = chemical of concern

HHRA = human health risk assessment

OU5 = Operable Unit 5

Table 3. Summary of the Calculated Lead Sediment PRGs

Tar Creek Superfund Site Operable Unit 5 Remedial Investigation

Ottawa County, Oklahoma

Receptors	Scenario	Age Group	Soil/Sediment Ingestion (mg/day)	SW Ingestion (L/day)	SW EPC (µg/L)	Dietary Intake (µg/day)	Time Weighted Average	Exposure Frequency at OU5 (day/week)[e]	EPC at Residential Yard (mg/kg)	PRGs (mg/kg) BLL=5	BLL=8	BLL=10
General Public	High-End Exposure†	12-72 mo.[a]	Default (52 - 94)	Default (0.43 - 0.60)	Bkgd mean [total]	Default	No	Daily Sediment Exposure		178	420	590
							Yes[c]	1[d]	151[d,f]	340	2,034	3,224
Tribal Lifeway	High-End Exposure‡	12-72 mo.[a]	RME (400)	RME (0.78)	Bkgd mean [total]	All food (100%)[b]	No	Daily Sediment Exposure		15	60	91
							Yes[c]	5[e]	151[e,f]	n/v	24	67
	Hybrid Exposure Scenario[a]	12-36 mo.[g]	Default (52 - 94)	Default (0.43 - 0.51)	TWA (1.94)[i]	All Food (25%)[b]	Yes	5[e]	151[e,f]	414	1,218	1,802
		36-72 mo.[h]		RME (0.78)								

Notes:

† The scenario corresponds to the high-end exposure scenario evaluated for the GP child in the HHRA.

‡ The scenario closely corresponds to the high-end exposure scenario evaluated for the TLW child in the HHRA.

[a] PRGs are calculated for the CDC's recommended age range (12 to 72 months old).

[b] The PRGs are calculated using the "Alternate Dietary Value" option, accounting for all food categories sampled from OU5 (i.e., fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant). Lead concentration in meat/fish (total) and vegetables and percentage of food originating from OU5 are entered into the model.

[c] The PRGs calculated for the high-end exposure scenario for the GP and TLW child are refined using the TWA approach.

[d] The GP child is assumed to visit OU5 once a week and is expected to be exposed to residential yard soil at the lead EPC of 151 mg/kg on the days when they do not visit OU5.

[e] The TLW child is assumed to visit OU5 5 days a week and is expected to be exposed to residential yard soil at the lead EPC of 151 mg/kg on the days when they do not visit OU5

[f] Based on the 95th percentile of the mean lead concentration calculated based on a dataset composed of 233 residences in Quapaw, Oklahoma.

[g] The younger age children (12-36 months old) are assumed to be exposed to lead at their residence only through incidental ingestion of yard soil and drinking water.

[h] Lead exposure by the older age children (36-72 months old) is assessed by addressing exposure both at OU5 and their residence using the TWA approach. They are assumed to visit OU5 5 days a week.

[i] The water EPC of 1.94 µg/L is a TWA based on exposure frequency and EPC in each exposure area and is calculated as below. The TWA EPC is used conservatively for both the younger and older age child groups.

EPC (1.94 µg/L) = EPC_{RES} (0.9 µg/L; IEUBK default) * (2/7) + EPC_{OU5} (2.35 µg/L bkgd mean [total]) * (5/7).

n/v = Because of the lead intake through exposure to residential yard soil, no sediment PRG value can be calculated using the IEUBK model (i.e., even if lead concentration in sediment is zero, it would not achieve the target BLL).

µg/day = micrograms per day
µg/L = micrograms per liter
Bkgd = background
BLL = blood lead level
CDC = Centers for Disease Control and Prevention
EPC = exposure point concentration
GP = General Public
HHRA = human health risk assessment
L/day = liters per day
mg/day = milligrams per day
mg/kg = milligrams per kilogram
OU = Operable Unit
PRG = preliminary remediation goal
RME = reasonable maximum exposure
SW = surface water
TLW = Tribal Lifeway
TWA = time-weighted average

Table 4. Values and Equations Used in Cadmium and Zinc PRGs

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Exposure Factors	Exposure Factors Symbol	Units	TLW Child		Aquatic Worker	Equations
			Cd	Zn	Cd	
Exposure Frequency (Sediment Direct Contact)	EF_{DC}	day/year	312	312	250	
Exposure Frequency (Aquatic Plant Consumption)	EF_{AP}	day/year	365	365	n/a	
Exposure Duration	ED	year	6	6	25	
Body Weight	BW	kg_{BW}	15	15	70	
Average Time	AT_{NC}	days	2190	2190	9125	
Sediment Ingestion Rate	IR_{Sed}	mg/day	400	400	400	
Skin Surface Area	SA	cm^2	6365	6365	19652	
Sediment Adherence Factor	SSAF	mg/cm^2-day	0.1	0.1	0.1	
Dermal Absorption Factor	DABS (Cd only)	unitless	0.001	0.001	0.001	
Aquatic Plant Ingestion Rate	IR_{AP}	g/day	66.5	66.5	n/a	
Aquatic Plant Fraction Ingested	FI	unitless	0.25 or 1	0.25 or 1	n/a	
Reference Dose for Ingestion	RfDoral	mg/kg_{BW}-day	1.0E-03	3.0E-01	1.0E-03	
Reference Dose for Dermal Contact	RfDdermal	mg/kg_{BW}-day	2.5E-05	3.0E-01	2.5E-05	
Sediment PRG for ingestion route	PRGing	mg/kg_{sed}	43.9	13161	255.5	PRG_{ing} = (RfDoral * HI) / (IR_{Sed} * EF_{DC} * ED * 1E-6 * [1/BW] * [1/AT_{NC}])
Sediment PRG for dermal contact route	PRGderm	mg/kg_{sed}	689.2	n/a	1300.1	PRG_{Derm} = (RfDderm * HI) / (SA * SSAF * DABS * EF_{DC} * ED * 1E-6 * [1/BW] * [1/AT_{NC}])
Sediment PRG for direct contact pathway	PRG_{DC}	mg/kg_{sed}	41.2	13,161	214	PRG_{DC} = 1/ (1/PRG_{ing} + 1/PRG_{derm})
Aquatic Plant PRGS for Aquatic Plant Consumption Pathway (FI=1)	PRG_{AP}	mg/kg_{AP}	0.226	67.7	n/a	PRG_{AP} = (RfDoral * HI) / (IR_{AP} * EF_{AP} * ED * FI * 1E-3 * [1/BW] * [1/AT_{NC}])
Aquatic Plant PRGS for Aquatic Plant Consumption Pathway (FI=0.25)	PRG_{AP}	mg/kg_{AP}	0.902	271		
Regression Equation (Slope)	Slope	kg_{sed}/kg_{AP}	0.136	0.120		
Regression Equation (Intercept)	Int	mg/kg_{AP}	-1.64	-194.29		
Sediment PRG for Direct Contact and Aquatic Plant Consumption (FI=1)	PRG_{DC+AP}	mg/kg_{sed}	13.2	2,095		PRG_{DC+AP} = 1-(Int*(1/PRG_{AP})))/((1/PRG_{DC})+Slope*(1/PRG_{AP}))
Sediment PRG for Direct Contact and Aquatic Plant Consumption (FI=0.25)	PRG_{DC+AP}	mg/kg_{sed}	16.1	3,310		

Notes:

cm^2 = square centimeter

g = gram

kg_{AP} = kilograms of aquatic plant (wet weight)

kg_{BW} = kilograms of body weight

kg_{sed} = kilograms of sediment (dray weight)

mg = milligram

PRG = preliminary remediation goal

TLW = Tribal Lifeway

Table 5. Summary of the Calculated Cadmium and Zinc Sediment PRGs

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Exposure Scenario	**Cadmium**	**Zinc**
Aquatic Worker - direct contact pathway	214	**n/a**
Tribal Lifeway (child) - direct contact pathway	41.2	13,161
Tribal Lifeway (child) - direct contact + aquatic plant consumption (FI=0.25)	16.1	3,310
Tribal Lifeway (child) - direct contact + aquatic plant consumption (FI=1)	13.2	2,095
Ecological Risk Assessment PRG (T10)	11.1	2,083
Ecological Risk Assessment PRG (T20)	17.3	2,949

Notes:

Units are presented in milligrams of COCs per kilograms of sediment (dry weight).

COC = chemical of concern

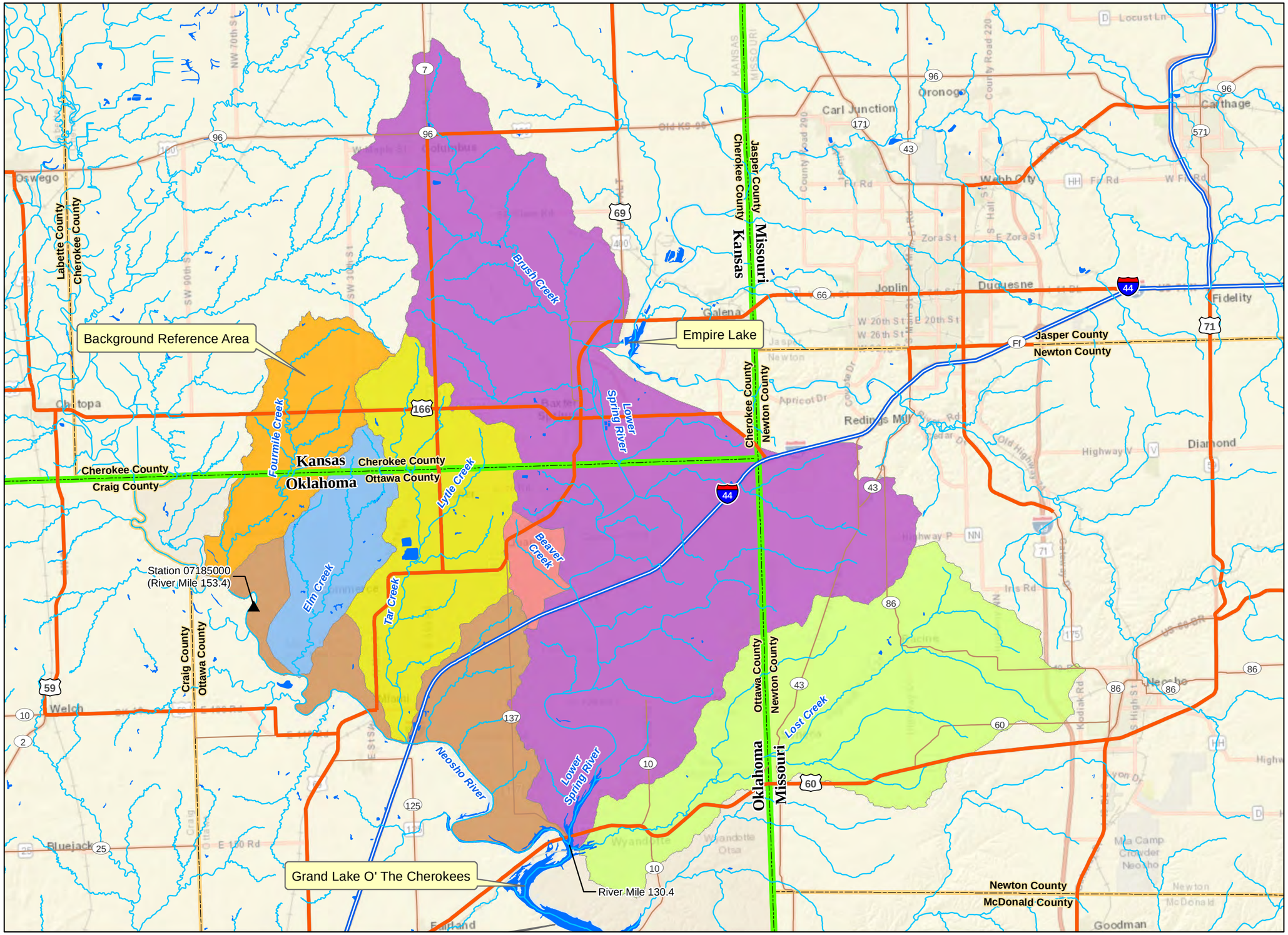
n/a = not applicable; zinc was not identified as a COC for Aquatic Worker

PRG = preliminary remediation goal

T10 - Site-specific toxicity threshold corresponding to 10% reduction in survival or biomass

T20 - Site-specific toxicity threshold corresponding to 20% reduction in survival or biomass

Figures



Legend

- USGS Stream Gage
- NHD Stream
- State Boundary
- County Boundary
- Fourmile Creek (Background/Reference Watershed)
- Elm Creek Watershed
- Tar Creek Watershed
- Neosho River Watershed
- Beaver Creek Watershed
- Lost Creek Watershed
- Lower Spring River Watershed

Notes:
1) Imagery Source: ESRI World Street Map online mapping service
2) Operable Unit 5 (OU5) does not have specific boundaries, but is defined by the extent of the watersheds that have been identified by the EPA as relevant to Tar Creek Superfund Site OU5.
3) River Mile 130.4 represents the downstream extent of the OU5 study area.

NHD = National Hydrography Dataset
USGS = U.S. Geological Survey

N

0 1.75 3.5 7 Miles

Figure 1.
Operable Unit 5 Watersheds
Tar Creek Superfund Site
Operable Unit 5
Ottawa County, Oklahoma

ch2m

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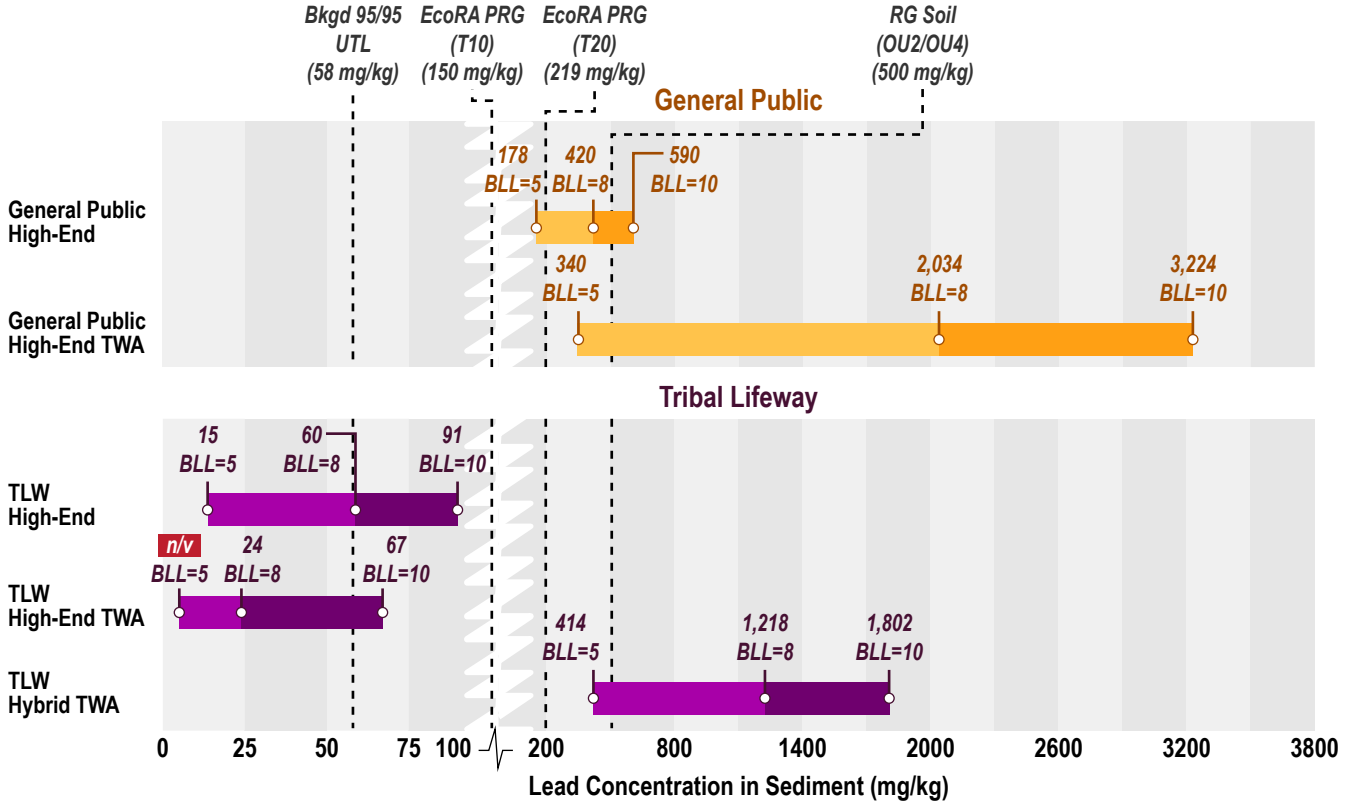
Figure 2. Estimated Lead PRGs Under Various Scenarios



	GENERAL PUBLIC		TRIBAL LIFEWAY				
	High-End Exposure †		High-End Exposure ‡		Hybrid Exposure Scenario		
Age Group	12–72 mo. (1)		12–72 mo. (1)		12–36 mo. (7)	36–72 mo. (8)	
Sediment/Soil Ingestion (mg/day)	Default (52–94)		RME (400)		Default (52–94)		
SW Ingestion (L/day)	Default (0.43-0.60)		RME (0.78)		Default (0.43–0.51)	RME (0.78)	
SW EPC (µg/L)	Bkgd mean [total] (2.35)		Bkgd mean [total] (2.35)		TWA (1.94) (9)		
Dietary Intake (µg/day)	Default (5.03–6.04)		All food (100%) (2)		All food (25%) (2)		
Exposure Area	OU5 only		OU5 only		PRGs are established for TWA scenario only		
Exposure frequency at OU5 (days/week)	Daily		Daily				
	High-End (TWA) (3)		High-End (TWA) (3)		Hybrid (TWA) (1,7,8)		
Exposure Area	OU5	Residence	OU5	Residence	Residence	OU5	Residence
Exposure frequency at OU5 (days/week)	1 (4)	6	5 (5)	2	7	5	2
Soil EPC at Residence (mg/kg)	n/a	151 (6)	n/a	151 (6)	151 (6)	n/a	151 (6)

mg/kg – milligrams per kilogram
mg/day – milligrams per day
L/day – liters per day
µg/L – micrograms per liter
µg/day – micrograms per day

Notes:

† The scenario corresponds to the high-end exposure scenario evaluated for the GP child in the HHRA.

‡ The scenario closely corresponds to the high-end exposure scenario evaluated for the TLW child in the HHRA.

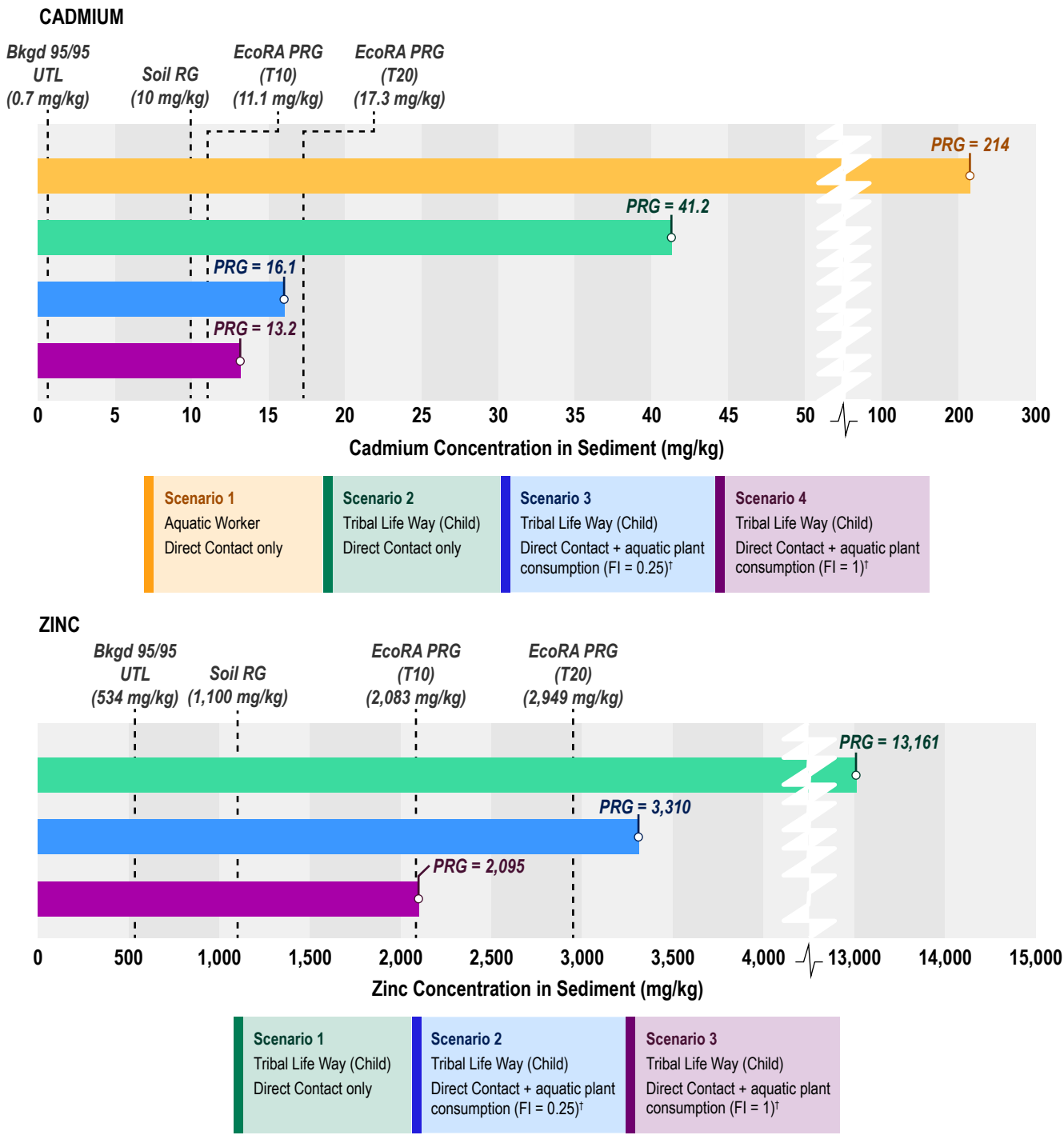
1. PRGs are calculated for the CDC's recommended age range (12–72 months old).
2. Using the 'Alternate Dietary Value' option, accounting for all food categories sampled from OU5.
3. The PRGs calculated for the high-end exposure scenario for the GP and TLW child are refined using the TWA approach.
4. The GP child is assumed to visit OU5 once a week and is expected to be exposed to residential yard soil at the lead EPC of 151 mg/kg on the days when they don't visit OU5.
5. The TLW child is assumed to visit OU5 five days a week and is expected to be exposed to residential yard soil at the lead EPC of 151 mg/kg on the days when they don't visit OU5.
6. Based on the 95th percentile of the mean lead concentration calculated based on a dataset composed of 233 residences in Quapaw, Oklahoma.
7. The younger age children (12–36 months old) are assumed to be exposed to lead at their residence only through incidental ingestion of yard soil and drinking water.
8. Lead exposure by the older age children (36–72 months old) is assessed by addressing exposure both at OU5 and their residence using the TWA approach. They are assumed to visit OU5 five days a week.
9. The water EPC of 1.94 µg/L is a TWA based on exposure frequency and EPC in each exposure area.

n/v – because of the lead intake through exposure to residential yard soil, no sediment PRG value can be calculated using the IEUBK model (i.e., even if lead concentration in sediment is zero, it would not achieve the target BLL).

Acronyms:

AAF - absolute absorption fraction
Bkgd - background
BLL - blood lead level
CDC - Centers for Disease Control and Prevention
EPC - exposure point concentration
EcoRA - ecological risk assessment
GP - general public
n/a - not applicable
n/v - no value
OU - operable unit
PRG - preliminary remediation goal
sed - sediment
SW - surface water
TLW - tribal lifeway
TWA - time weighted average
UTL - upper tolerance limit

Figure 3. Estimated Cadmium and Zinc PRGs Under Various Scenarios



† Sediment PRGs protective of aquatic plant consumption are calculated using the regression equations established based on the collocated sediment and aquatic plant data.

Acronyms:
Bkgd - background
EcoRA - ecological risk assessment
FI - fraction of aquatic plants ingested from OU5
HI - hazard index
mg/kg - milligram(s) per kilogram
OU - operable unit
PRG - preliminary remediation goal
T10 - Site-specific toxicity threshold corresponding to 10% reduction in survival or biomass
T20 - Site-specific toxicity threshold corresponding to 20% reduction in survival or biomass
TLW - tribal lifeway
UTL - upper tolerance limit

Appendix A
Detailed Lead PRG Methodology

Appendix A

Detailed Lead Preliminary Remediation Goal Methodology, Tar Creek Superfund Site, Operable Unit 5

This document describes an approach for the development of human health risk-based lead preliminary remediation goals (PRGs) for Tar Creek Superfund Site Operable Unit 5 (OU5)[1]. The objective is to develop sediment PRGs protective of human health, not only for direct sediment contact but also secondary exposure through direct contact of surface water and food consumption. The approach presented herein has been discussed with the U.S. Environmental Protection Agency (EPA) Region 6 remedial project manager for OU5 and EPA Region 6 and Region 7 risk assessors during a series of technical meetings. It also has been reviewed by the EPA Technical Review Workgroup (TRW) for Metals and Asbestos: Lead Committee. This document summarizes the sediment PRGs that were calculated based on the approaches discussed during the technical meetings and incorporates TRW Committee review comments (a copy of the TRW review memorandum is provided in Attachment 1).

1.0 Background

The OU5 Human Health Risk Assessment (HHRA) (CH2M, 2020a) addressed three potential exposure scenarios (Tribal Lifeway [TLW][2], Aquatic Worker, and General Public [GP]). The discussion presented herein primarily describes the approach for use of the Integrated Exposure Uptake Biokinetic (IEUBK) model for lead exposure by child receptors under the TLW and GP exposure scenarios. The potentially complete exposure pathways identified in the HHRA for these exposure scenarios for child receptors are summarized in Table 1.

The purpose of the lead analysis in the HHRA (CH2M, 2020a) was to identify the potential for unacceptable risk associated with exposure to lead in environmental media within the OU5 study area. Given the elevated concentrations of lead detected in OU5 media (e.g., average lead concentration in Elm Creek sediment is as high as 4,281 milligrams per kilogram [mg/kg]) and the limitations of the available lead models, a conscious effort was made to streamline the evaluation of potential lead exposures in the OU5 study area media without expending considerable effort in identifying precise exposure parameter values characterizing the unique OU5 study area exposure scenarios. The HHRA evaluated potential childhood lead exposure at OU5 under two separate analyses: (1) the analysis based on the reasonable maximum exposure (RME) values identified for the TLW child in the HHRA to assess the high-end lead exposure by TLW child, and (2) the analysis based on the default IEUBK input parameter values to assess the high-end of potential lead exposure by GP child.

Tribal members and citizens are a stakeholder group with a strong interest in the OU5 HHRA. Stakeholder input has been received since the beginning of the project and was critical in developing the scope and model input parameters of the HHRA. It should be noted that the approach of sediment PRG development established with EPA Region 6 is considered highly conservative because sediment samples were collected from perennially flowing creeks, streams, and rivers, and sediment attached to skin surface is expected to be readily washed off when receptors are out of the water. Some of the EPA regions have an established policy of not evaluating exposure to sediment perennially covered with

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[1] OU5 is defined by EPA Region 6 as sediments and surface water between the stream banks in perennially flowing creeks, streams, and rivers that may be impacted by historical mining activities at the Tar Creek Superfund Site.

[2] The TLW exposure scenario reflects potential exposure pathways associated with subsistence practices by tribal members and citizens in the communities surrounding OU5.

water for this reason. For instance, EPA Region 4 (2018) has long followed a policy of only quantifying human exposure to sediment that is not covered by water (for example, sediment in an intermittent stream for the portion of the year the stream is without water) and generally considers it unnecessary to evaluate human exposure to sediments that are always covered by surface water, while EPA Region 1 evaluates only sediments and water to about knee depth.

It is acknowledged that in addition to the inherent uncertainty associated with RME exposure values identified in the HHRA, there are considerable uncertainties associated with the use of the upper-end exposure parameter values (such as RME values) in the IEUBK model, since the model is designed to predict the cumulative distribution of blood lead levels (BLLs) based on central tendency exposure parameter values. Therefore, the two analyses discussed above are intended to provide the potential high-end lead exposure and risk outcomes for each corresponding receptor scenario.

Based on the results of the lead exposure analyses, the HHRA concluded that potential lead exposure at OU5 leads to a level above the target lead exposure criterion (i.e., more than 5% probability of exceeding the target BLL of 5 micrograms per deciliter [µg/dL]) and lead was thus identified as a preliminary chemical of concern in all six OU5 watersheds. Additionally, the lead exposure estimated based on the exposure point concentrations (EPCs) at the reference watershed (Fourmile Creek, which represents background lead concentrations in sediment and surface water) also exceeds the target lead exposure criterion. Concentrations of lead in sediment and surface water at two of the watersheds (Neosho River and Lost Creek) are comparable to background; therefore, lead was identified as the final chemical of concern in all watersheds (Elm Creek, Tar Creek, Beaver Creek, and Lower Spring River) except these two watersheds.

2.0 Approach for Lead PRG Development

In addition to the approach used for the HHRA, the development of a potential PRG for lead in sediment considers a wider range of potential exposure assumptions to provide risk managers with a range of potential outcomes for decision-making. Two sets of the IEUBK model runs were performed for the lead PRG development. Brief descriptions of each set of the model runs are provided below. The information regarding how the OU5 exposure pathways are evaluated and specific exposure assumptions used in the IEUBK modeling are summarized in Table 2. All of the IEUBK model runs used target BLLs of 5, 8 and 10 µg/dL, consistent with the lead exposure analyses in the HHRA (CH2M, 2020a).

- Set 1 – Assumes total lead exposure from OU5 exposure media plus non-OU5-related sources using varying input parameter values to assess potential ranges of sediment PRGs. This set of PRGs was developed based on the general approach and exposure assumptions used in the lead exposure analysis in the HHRA. The three key exposure pathways (sediment ingestion, surface water ingestion, and food consumption [i.e., dietary intake]) that are associated with OU5 and expected to be the most influential on PRG values are focused on in this set. The sediment PRG based on the IEUBK default values and the site-specific EPC for surface water is considered the high-end of the potential PRG range for the GP child and reflects the scenario evaluated in the HHRA. The sediment PRG based on the tribal RME parameter values (e.g., sediment ingestion rate of 400 milligrams per day [mg/day]) is considered the high-end of the PRG range for the TLW child, reflecting the scenario evaluated in the HHRA. In this set of PRGs, sediment exposure is treated as soil exposure and surface water exposure is treated as drinking water in the model (i.e., assumed daily exposure to OU5 sediment and surface water without considering receptors' exposure frequency at OU5) and the calculated soil PRGs are presented as sediment PRGs.
- Set 2 (scenarios incorporating residential exposure) – Assumes total lead exposure from OU5 exposure media plus non-OU5-related sources (for example, exposure to lead in residential yard soil), but uses a time-weighted average (TWA) approach. The TWA approach was used to account for lead exposure in two exposure areas (exposure at OU5, and exposure at their residence) using

the assumed frequency of OU5 visits and additional lead exposure to soil at their residential yards (or drinking water).

- The first set of PRGs (Set 2a) further refines the high-end PRGs calculated in Set 1 by incorporating frequency of visit to OU5 and lead intake through incidental ingestion of soil in residential yards.
- The second set of PRGs (Set 2b) was calculated for the TLW child only based on assumed exposure scenarios distinctive for two child age groups. Like Set 2a, lead intake through sediment/soil and water in two exposure areas (exposure at OU5, and exposure at residential yards) is estimated using the TWA approach. However, under this set of the PRGs, OU5 medium-related exposures are addressed only for the older child age group that is most likely to visit OU5 and to engage in the expected TLW activities; while the PRGs also incorporated the younger child's exposure to residential yard soil and drinking water. Further, to address a potential increase in bioavailability of lead in OU5 sediment, an additional set of sediment PRGs was calculated based on an absolute absorption fraction (AAF) of lead in soil/dust of 40% (in comparison to the IEUBK default AAF of lead in soil/dust of 30%). The AAF of 40% is selected as an expected high-end of AAF of lead in OU5 sediment.

3.0 Methods

3.1 Set 1 (High-End Scenarios)

To initially assess the sensitivity of key input variables, a preliminary assessment of sediment PRGs was performed for each of the three key exposure pathways (sediment ingestion, surface water ingestion, and food consumption [i.e., dietary intake]). The model was run multiple times using varying input values (from the IEUBK default values to the RME parameter values identified for the TLW child in the HHRA) for these key pathways, while all other values (outdoor/indoor air inhalation) were set at the IEUBK model defaults. Implicit in this set of PRGs is the assumption that OU5 sediments are brought home and children are then exposed to lead in the form of dust ingestion and through inhalation of lead in indoor and outdoor air. A summary of the IEUBK input parameter values used in the sensitivity analysis is presented in Table 3. The IEUBK modeling approach and descriptions of the input parameter values in the sensitivity analysis are provided in Attachment 2 in more detail. Based on the findings in the sensitivity analysis, PRGs calculated for select scenarios are presented in Table 4. The sediment PRGs in Set 1 are calculated based on the Centers for Disease Control and Prevention (CDC)-recommended age range of 12 to 72 months old (EPA, 2017).

- **Sediment exposure:** The model was run using the IEUBK default values (ranging from 52 to 94 mg/day for various age groups) and an RME sediment ingestion rate of 400 mg/day (i.e., the RME sediment ingestion rate identified based on Harper [2008] in the HHRA). The scenario using the RME sediment ingestion rate of 400 mg/kg is included in the PRG development solely to reflect the scenario evaluated in the HHRA (Scenario 5 in Table 4). The TRW Lead Committee does not consider 400 mg/day to be a central tendency soil-dust ingestion rate for a human child receptor and considers the Harper et al. (2007) report used as the basis of the ingestion rate to be outdated. Therefore, an additional set of PRGs are calculated using a sediment ingestion rate of 200 mg/day (Scenario 4 in Table 4).
- **Surface water exposure:** The model was run using the IEUBK default values (ranging from 0.43 to 0.60 liter per day [L/day] for various age groups) and an RME surface water ingestion rate of 0.78 L/day (EPA's RME default drinking water ingestion rate [EPA, 2014]). The RME ingestion rate is assumed to account for three TLW exposure pathways: (1) incidental ingestion through hunting/fishing/gathering and recreational activities, (2) ingestion of surface water as a drinking water source, and (3) ingestion of surface water during sweat lodge use. The background mean lead concentration (2.35 micrograms per liter [µg/L]) is used as the EPC in surface water. Due to the lack

of media transfer information between sediment and surface water, it is assumed that surface water concentrations (for lead) will be comparable to background following sediment remediation.

- **Dietary exposure:** Dietary lead intake is estimated using the IEUBK model's "Alternate Dietary Values" option based on the lead concentration in OU5 food and percentage of food originating from OU5, rather than the dietary lead intake estimated based on the RME dietary ingestion rates identified in the HHRA. Background mean concentrations are used as the EPC in biota (Table 6). Due to the lack of media transfer information between sediment and biota, it is assumed that lead concentrations in biota will be comparable to background following remediation of sediment. The weighted average lead concentration in meat/fish (0.127 microgram per gram [µg/g]), accounting for all food categories sampled from OU5 (fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal) and the lead concentration in aquatic plant (0.11 µg/g) in background samples are used in the calculations (Table 6). The percentage of food originating from OU5 is estimated to be specific percentages (25% or 100%) of all meat/fish and all vegetables that the receptors consume.

3.2 Set 2 (Scenarios Incorporating Residential Exposure)

The TLW and GP children were assumed to contact sediment and surface water at OU5 for only part of a week (unlike continuous soil exposure at a residential setting). This set of PRGs was estimated using a TWA approach, which accounts for lead exposure in two exposure areas (exposure at OU5, and exposure at their residence) based on the assumed portion of time spent at each area. This set adjusts PRGs for frequency of OU5 visits and additional lead exposure to soil at their residential yards (or drinking water) (Table 5).

3.2.1 Set 2a (Refinement of the High-End Scenario PRGs in Set 1)

The PRGs calculated in Set 1 (the high-end exposure scenarios for the TLW and GP children) were further refined using a TWA approach. An exposure frequency of 1 day per week (day/week) is used for GP child, which corresponds to the RME exposure frequency used in the HHRA[3]. Two exposure frequencies of 2 and 5 days/week are used for the TLW child. An exposure frequency of 5 days/week roughly corresponds to the RME exposure frequency of 234 days/week used in the HHRA. A lead EPC of 151 mg/kg (95th percentile of the mean lead concentration based on a dataset composed of 233 Quapaw residences) is used to represent lead concentrations in residential yard soil. Sediment PRGs are calculated using the TWA approach based on the general equations presented below.

$$PRG_{Soil-Sed} = PRG_{Sed} \times EF_{OU5} + EPC_{Soil} \times EF_{Res}$$

$$PRG_{Sed} = \frac{PRG_{Soil-Sed} - EPC_{Soil} \times EF_{Res}}{EF_{OU5}}$$

Where:

$PRG_{Soil\text{-}Sed}$ (mg/kg) = PRG estimated in Set 1 without considering frequency of OU5 exposure and exposure at residential yards

PRG_{Sed} (mg/kg) = Sediment PRG estimated using the TWA

EPC_{Soil} (mg/kg) = Lead concentration in residential yard soil

EF_{OU5} (unitless) = Frequency of exposure at OU5 (e.g., 5 days/week or 0.71)

EF_{Res} (unitless) = Frequency of exposure at residential yards (e.g., 2 days/week or 0.29)

[3] The RME exposure frequency (28 days/week) is based on an assumption that a GP child visits OU5 once a week during the 7 months between April and October.

3.2.2 Set 2b (Hybrid Scenario Incorporating Exposure Characteristics of Two Child Age Groups)

An additional scenario was evaluated for the TLW child based on an assumed exposure characterization distinctive of two child age groups. As done in Set 2a, two exposure areas were considered (exposure at OU5, and exposure at their residence). The older children (3 to 6 years old) are assumed to be the primary age groups who visit OU5 to engage in TLW activities (hunting/fishing/gathering and recreation). It was assumed that lead exposure by the younger children (1 to 3 years old) takes place primarily at their residence and direct exposure to sediment and surface water at OU5 is negligible. The model was run for the CDC's entire recommended age range (1 to 6 years old) (EPA, 2017) and accounts for the younger-age child's exposure at their residence and older-age child's exposure at OU5 and at their residence. Further, consistent with the assumption of the high-end OU5 exposure frequency in Set 2a, the older TLW child is assumed to spend 5 days/week at OU5 and stay at home for the rest of days in week (2 days/week). The descriptions of the input parameter values used for this set of PRGs are provided in the following bullet section for each exposure medium; specific model input parameters are provided in Table 5.

- **Sediment exposure:** Combined soil and sediment exposure is assumed to occur at the IEUBK's default ingestion rate. It is assumed that the younger child (12 to 36 months old) is exposed to lead at their residence only. Their exposure is characterized with daily lead exposure at the IEUBK's default soil ingestion rate and lead EPC of 151 mg/kg (95th percentile of the mean lead concentration based on a dataset composed of 233 Quapaw residences). The older child is assumed to visit OU5 at a frequency of 5 days/week and stay at home for the rest of the days in week (2 days/week). The IEUBK's "Variable Values" option is selected, and a residential yard soil EPC of 151 mg/kg is entered for the younger age groups (0 to 1, 1 to 2, and 2 to 3 years old). The model was run multiple times[4] to identify the TWA soil/sediment concentration corresponding to each of the target BLLs for older age groups (3 to 4, 4 to 5, 5 to 6, and 6 to 7 years old). Screen shots of the model input interface are presented in Attachment 3. The TWA concentration identified from the model runs is entered into the equation and sediment PRGs are calculated based on the exposure frequency (5 days/week) and lead EPC in a residential yard (151 mg/kg) (Table 5).
- **Surface water exposure:** It is assumed that the younger child (12 to 36 months old) is exposed to lead through consumption of drinking water at their residence only. Their exposure is characterized with daily lead exposure at the IEUBK's default water ingestion rate and lead EPC of 0.9 µg/L (IEUBK's default lead concentration in drinking water). The older child (36 to 72 months old) is assumed to have an increased water ingestion due to additional water contact at OU5 and during sweat lodge use. Therefore, an RME water ingestion rate of 0.78 L/day is used. They are assumed to visit OU5 at a frequency of 5 days/week and be exposed to surface water with an EPC of 2.35 µg/L (background mean lead concentration)[5], and stay at home for the rest of the week (2 days/week) and be exposed to lead at an EPC of 0.9 µg/L. The TWA water concentration of 1.94 µg/L is calculated and used as the lead EPCs in water (Attachment 3).
- **Dietary exposure:** Dietary lead intake is estimated using the IEUBK model's "Alternate Dietary Values" option based on the lead concentration in OU5 food and the percentage of food originating from OU5.
  - Background mean concentrations are used as the EPC in biota. Due to the lack of media transfer information between sediment and biota, it is assumed that lead concentrations in biota will be comparable to background following remediation of sediment. The weighted average lead

[4] The model was run for the CDC's recommended age range (12 to 72 months old), assuming the same child would be exposed to lead from ages 1 through 6 years old under the two exposure scenarios identified for the two age groups: younger ages (residential exposure only) and older ages (exposure both at OU5 and their residential yard).

[5] Due to the lack of media transfer information between sediment and surface water, it is assumed that surface water concentrations (for lead) will be comparable to background following sediment remediation.

concentration in meat/fish (0.127 µg/g), accounting for all food categories sampled from OU5 (fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal) and the lead concentration in aquatic plant (0.11 µg/g) in background samples are used in the calculations (Table 6).

– Percentage of OU5-related food originating from OU5 is estimated to be 25% for all meat/fish and all vegetables that the receptors consume.

- **Dust ingestion and outdoor/indoor air exposure:** The lead exposure associated with dust ingestion and outdoor/indoor air exposure is incorporated into the PRGs. The lead in indoor dust was estimated using the IEUBK's multisource analysis function and default outdoor concentration (0.1 microgram per cubic meter), and the percentage of indoor air lead concentration to outdoor air concentration (30%) was used.
- **AAF of lead in soil and dust:** To address a potential increase in bioavailability of lead in OU5 sediment, an additional set of sediment PRGs was calculated based on an AAF of lead in soil/dust of 40% (in comparison to the IEUBK default AAF of lead in soil/dust of 30%). The AAF of 40% is selected as an expected high-end of AAF of lead in OU5 sediment.

4.0 Results

The results of each set of IEUBK model runs are summarized in Tables 4 and 5 and are graphically presented on Figures 1 and 2. Among the input variables, sediment ingestion rate is the most influential parameter on the sediment PRG. All the scenarios using a sediment ingestion rate of 400 mg/day yield a PRG lower than the lead background threshold value of 59 mg/kg based on a target BLL of 5 µg/dL. For the scenarios using a sediment ingestion rate of 400 mg/day, a reduced soil/dust absorption fraction (20%) (Attachment 2), or a TWA approach accounting for a fraction of exposure at OU5 (Table 5), the sediment PRG does not noticeably increase above the background threshold value. The PRGs calculated under the hybrid scenario incorporating exposure characteristics of two child age groups (Set 2b in Table 5) are the preferred PRGs and reflect the TRW Committee's comments and recommendations. Under this scenario, the PRGs calculated with both default and high-end AAFs based on a target BLL of 5 µg/dL are greater than the Ecological Risk Assessment PRGs of 150 mg/kg (T10) and 209 mg/kg (T20), which correspond to a site-specific toxicity threshold corresponding to a 10% and 20% reduction in survival or biomass, respectively (CH2M, 2020b).

5.0 References

CH2M. 2020a. *Tar Creek Superfund Site Operable Unit 5. Ottawa County, Oklahoma. Human Health Risk Assessment. DCN: 0079-02017.* May.

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Tables

Appendix A. Table 1. Summary of Exposure Scenarios Evaluated in the HHRA

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Exposure Medium	Exposure Scenario/Receptor Population	
	Tribal Lifeway	**General Public**
Sediment	Hunting/fishing/gathering and recreational activities • Incidental ingestion • Dermal contact	Recreational activities • Incidental ingestion • Dermal contact
Surface Water	Hunting/fishing/gathering and recreational activities • Incidental ingestion • Dermal contact Potable source • Ingestion • Dermal contact Sweat lodge use • Ingestion • Dermal contact • Inhalation (water vapor)	Recreational activities • Ingestion • Dermal contact Potable source • Ingestion • Dermal contact
Mine Discharge	Hunting/fishing/gathering and recreational activities • Dermal contact	Recreational activities • Dermal contact
Fish Tissue (Estimated whole fish concentrations)	• Food consumption	
Fish Tissue (Game Fish Fillet)		Recreational Fishing • Food consumption
Shellfish Tissue (Mussel and Asian Clam)	• Food consumption	
Aquatic Plant as Food (Arrowhead and Duckweed)	• Food consumption	
Aquatic Plant as Salve (Arrowhead)	• Dermal contact (medicinal use)	
Amphibian/Aquatic Reptile Tissue (Frog Legs)	• Food consumption	
Semi-Aquatic Mammal Tissue (Raccoon)	• Food consumption	

Note:

The table presents exposure scenarios/pathways for child receptors only.

HHRA = human health risk assessment

Appendix A. Table 2. Summary of Exposure Assumptions Used in Different Sets of PRG Development

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Exposure Medium/ Pathway	TLW							GP			
	Exposure Scenario	Exposure Route	Set 1[1] (and Set 2a)[2] (High-End Exposure Scenario)[3]		Set 2b (Hybrid Exposure Scenario)[4]			Exposure Scenario	Exposure Route	Set 1[1] (and Set 2a)[2] (High-End Scenario)[3]	
			Is pathway addressed in the IEUBK modeling?	Modeled Age Group: 12-72 mo.[5] Assumptions	Modeled Age Group: 12-72 mo.[5] Is pathway addressed in the IEUBK modeling? 12-36 mo.[6]	36-72 mo.[6]	Assumptions			Is pathway addressed in the IEUBK modeling?	Modeled Age Group: 12-72 mo.[5] Assumptions
Sediment	Hunting/fishing/ gathering and recreational activities	Incidental Ingestion	Yes	An RME ingestion rate of 400 mg/day represents daily sediment exposures through incidental ingestion at OU5 during the TLW activities and secondary exposure at home (including dust ingestion)	No	Yes	Younger child (12-36 mo. old) is exposed to soil in residential yards only, while older child (36-72 mon. old) is exposed to lead both through incidental ingestion of residential yard soil and sediment at OU5. The older child is exposed to OU5 sediment 5 days/week.	Recreational activities	Incidental Ingestion	Yes[1]	The default soil ingestion rates represent daily sediment exposures through incidental ingestion at OU5 during the recreational activities and secondary exposure at home (including dust ingestion)
		Dermal[8]	No		No	No			Dermal[8]	No	
	Exposure at home * Not included in the CEM[9]	Incidental Ingestion (indoor dust)	Yes		Yes	Yes		Secondary exposure at home * Not included in the CEM[9]	Incidental Ingestion (indoor dust)	Yes[1]	
		Dermal[8]	No		No	No			Dermal[8]	No	
Surface Water[7]	Hunting/fishing/ gathering and recreational activities	Incidental Ingestion	Yes	An RME ingestion rate of 0.78 L/day represents daily surface water ingestion through incidental ingestion at OU5 during the TLW activities, potable use of SW, and ingestion of SW during sweat lodge use	No	Yes	Younger child (12-36 mo. old) is exposed to lead through consumption of drinking water only, while older child (36-72 mon. old) is exposed to lead both through drinking water consumption and incidental ingestion of SW at OU5. The older child is exposed to OU5 sediment 5 days/week.	Recreational activities	Incidental Ingestion	Yes[2]	The default drinking water ingestion rates represent daily surface water ingestion through incidental ingestion at OU5 during the recreational activities and potable use of SW.
		Dermal[8]	No		No	No			Dermal[8]	No	
	Potable Use	Ingestion	Yes		Yes	Yes		Potable Use	Ingestion	Yes[2]	
		Dermal[8]	No		No	No			Dermal[8]	No	
	Sweat Lodge Use	Ingestion	Yes		No	Yes		n/a			
		Dermal[8]	No		No	No					
		Inhalation	Yes	Inhalation of lead in water vapor is addressed by inhalation of lead in outdoor/indoor air.	Yes	Yes	Inhalation of lead in water vapor is addressed by inhalation of lead in outdoor/indoor air.				
Mine Discharge	Direct Contact	Dermal[8]	No		No	No		Direct Contact	Dermal[8]	No	
Diet[7]	Fish	Ingestion	Yes	Dietary intake of lead through food consumption was evaluated based on the lead concentrations in background data sets. It is assumed that 100 % vegetables and meat they consume are originated from OU5.	Yes	Yes	Dietary intake of lead through food consumption was evaluated based on the lead concentrations in background data sets. It is assumed that 25 % vegetables and meat they consume are originated from OU5.	Fish	Ingestion	Yes	The default dietary lead intake represents lead exposure through consumption of fish.
	Shellfish	Ingestion	Yes		Yes	Yes		n/a			
	Aquatic Plant	Ingestion	Yes		Yes	Yes					
	Amphibians	Ingestion	Yes		Yes	Yes					
	Small Mammal	Ingestion	Yes		Yes	Yes					
	Aquatic Plant (medicinal)	Dermal[8]	No		No	No					
Air	* Not included in the CEM[9]	Inhalation (outdoor and indoor air)	Yes	Inhalation of lead in water vapor is addressed by inhalation of lead in outdoor/indoor air.	Yes	Yes	Inhalation of lead in outdoor/indoor air is accounted for in the PRG value.	* Not included in the CEM[9]	Inhalation (outdoor and indoor air)	Yes	Inhalation of lead in outdoor/ indoor air is accounted for in the PRG value.

Notes:

(1) Because the IEUBK model is designed primary for evaluation of residential soil and drinking water exposures, there is no specific way of addressing partial, intermittent exposure of lead in sediment or surface water.

Therefore, in PRGs calculated in Set 1, sediment is treated simply as soil and surface water is treated as drinking water.

(2) Set 2a PRGs refine Set 1 PRGs (the high-end exposure scenarios for TLW and GP children) using the time weighted average approach (which accounts for exposure frequency at OU5 and lead exposure through ingestion of residential yard soil).

(3) High-end exposure scenarios in Set 1 (Scenarios 1 and 5) correspond to the lead exposure analyses evaluated in the HHRA (Appendix E of CH2M, 2020) for GP and TLW receptors, respectively.

(4) PRGs calculated using the hybrid approach (residential exposure for the younger age children [12-36 months old] and residential and OU5 exposures for the older age children [36-72 months old]).

(5) PRGs are calculated for the CDC's recommended age range (12 to 72 months old).

(6) Younger age children (12-36 months old) are assumed to be exposed to lead at their residence only through incidental ingestion of yard soil and drinking water, while TWA approach is used to assess older age children (36-72 months old) exposure at OU5 and their residence.

(7) Due to the lack of media transfer information of lead between sediment and surface water or sediment and biota, it is assumed that lead concentrations in surface water and biota will be comparable to background levels following sediment remediation.

(8) Dermal exposure is not addressed in the IEUBK model.

(9) The exposure scenario is not included in the OU5 HHRA CEM and non-lead COPCs (e.g., cadmium and zinc) are not evaluated for this exposure pathway.

Acronyms:

CDC = Centers for Disease Control and Prevention
CEM = Conceptual Exposure Model
COPC = Chemical of Potential Concern
HHRA = human health risk assessment
IEUBK = Integrated Exposure Uptake Biokinetic Model
n/a = not applicable
PRG = Preliminary Remediation Goal
RME = Reasonable Maximum Exposure
SW = surface water
TLW = tribal lifeway
GP = General Public
OU = Operable Unit
L/day = liters per day

CH2M. 2020. Tar Creek Superfund Site Operable Unit 5. Ottawa County, Oklahoma. Human Health Risk Assessment. DCN: 0079-02017. May.

Appendix A. Table 3. Key Input Parameter Variables Evaluated in the Sensitivity Analysis

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Medium	Parameter	Value	Reference
Soil/Sediment	Soil/Sediment Ingestion Rate (mg/day)[1]	52 - 94	IEUBK default (12-72 months old)
		100	[1]
		200	[1]
		300	[1]
		400	Based on Soil Ingestion Rate in Harper (2008)
	Absorption Fraction (percent)[2] (soil/dust)	30%	IEUBK default
		25%	[2]
		20%	[2]
Surface Water	SW Ingestion Rate (L/day)	0.43 - 0.60	IEUBK default (12-72 months old)
		0.78	EPA RME default (2014)
	SW EPC (µg/L)	0.9	IEUBK default
		1.63	Bkgd mean [dissolved][3]
		2.35	Bkgd mean [total][3]
Diet	Dietary Intake (µg/day)[3]	5.03 – 6.04	IEUBK default (12-72 months old)
		13.6 – 17.6	Bkgd mean and RME ingestion rates (12-72 months old)[4a]
		25% (fish only)	Bkgd mean[4b]
		25% (all food)	Bkgd mean[4c]
		100% (all food)	Bkgd mean[4c]

Notes:

1) The sensitivity of soil/sediment ingestion rate is evaluated by increasing the rate by an increment of 100 mg/day.

2) The potential impact of absorption fractions on PRGs is assessed using arbitrary absorption fractions of 20% and 25%.

3) Due to the lack of media transfer information between sediment and surface water, it is assumed that lead concentrations in surface water will be comparable to background levels following sediment remediation.

4) Dietary lead intake is estimated in two ways: Approach based on estimated dietary lead intake or approach using the 'Alternate Dietary Values' option. Due to the lack of media transfer information between sediment and biota, it is assumed that lead concentrations in biota will be comparable to background levels following sediment remediation.

Approach based on estimated dietary intake:

a. The PRGs are calculated entering dietary lead intake values calculated based on background mean concentrations and RME ingestion rates (Table 6)

Approach using the 'Alternate Dietary Values' option:

b. The PRGs are calculated using the 'Alternate Dietary Values' option and entering lead concentration in fish (fillet) and percentage of fish originating from OU5. The average lead concentration in background fish fillet samples (0.116 µg/g) are used in the calculations (Table 6).

c. The PRGs are calculated using the 'Alternate Dietary Values' option, accounting for all food categories sampled from OU5 (i.e., fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant). Lead concentrations in meat/fish (total) and vegetables and percentage of food originating from OU5 are entered into the model. The weighted average lead concentration in meat/fish (0.127 µg/g) and the lead concentration in aquatic plant (0.11 µg/g) in background samples are used in the calculations (Table 6).

Acronyms:

Bkgd = background

EPA = U.S. Environmental Protection Agency

EPC = exposure point concentration

IEUBK = Integrated Exposure Uptake Biokinetic

RME = Reasonable Maximum Exposure

SW = surface water

Units

L/day = liters per day

mg/day = milligrams per day

µg/L = micrograms per liter

µg/day = micrograms per day

Reference

Harper, Barbara. 2008. *Quapaw Traditional Lifeways Scenario.* Prepared by Barbara Harper, PhD, DABT. AESE, Inc.

EPA. 2014. *Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors.* OSWER Directive 9200.1-120. February.

Appendix A. Table 4. Estimated PRGs Under Various Scenarios (Set 1)

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Scenarios	Age Group[1]	Soil/Sediment Ingestion[2] (mg/day)	SW Ingestion (L/day)	SW EPC (µg/L)	Dietary Intake (µg/day)	PRGs[3] (mg/kg) BLL=5	BLL=8	BLL=10
All default	12-72 mo.	default (52-94)	default (0.43 - 0.60)	default (0.9)	default (5.03 – 6.04)	199	439	609
Scenario 1 (GP)†	12-72 mo.	default	default	Bkgd mean [total] (2.35)	default	178	420	590
Scenario 2	12-72 mo.	default	RME (0.78)	Bkgd mean [total] (2.35)	default	162	402	572
Scenario 3	12-72 mo.	RME (400)	RME (0.78)	Bkgd mean [total] (2.35)	default	25	70	101
Scenario 4	12-72 mo.	IR (200)	RME (0.78)	Bkgd mean [total] (2.35)	All food (25%)[4]	75	164	226
Scenario 5 (TLW)‡	12-72 mo.	RME (400)	RME (0.78)	Bkgd mean [total] (2.35)	All food (100%)[4]	15	60	91

Notes:

† The scenario corresponds to the high-end exposure scenario evaluated for the GP child in the HHRA.

‡ The scenario closely corresponds to the high-end exposure scenario evaluated for the TLW child in the HHRA.

(1) PRGs are calculated for the CDC's recommended age range (12 to 72 months old).

(2) Default soil/dust absorption fraction of 30% is used for sediment.

(3) PRGs are presented in the nearest whole number corresponding to each of the target BLLs.

(4) Using the 'Alternate Dietary Value' option, accounting for all food categories sampled from OU5 (i.e., fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant). Lead concentration in all meat/fish (total) and all vegetables and percentage of food originating from OU5 (either 25% or 100%) are entered into the model. The weighted average lead concentration in meat/fish (0.127 µg/g) and the lead concentration in aquatic plant (0.11 µg/g) in background samples are used in the calculations (see Table 6).

Acronyms:
Bkgd = background
BLL = blood lead level
CDC = Centers for Disease Control and Prevention
EPC = exposure point concentration
GP = general public
IR = ingestion rate
OU = Operable Unit
PRG = Preliminary Remediation Goal
RME = Reasonable Maximum Exposure
SW = surface water
TLW = tribal lifeway

Units
L/day = liters per day
mg/day = milligrams per day
µg/day = micrograms per day
µg/g = micrograms per gram
µg/L = micrograms per liter

Appendix A. Table 5. Estimated PRGs Incorporating Residential Exposure Using Time Weighted Average Approach (Set 2)

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

								PRGs[3,4] (mg/kg)					Sediment PRGs[4,6] (mg/kg)		
Set	**Scenarios**	**Age Group[2]**	**Soil/Sediment Ingestion (mg/day)**	**SW Ingestion (L/day)**	**SW EPC (µg/L)**	**Dietary Intake (µg/day)**	**Absorption Fraction (%)**	**BLL=5**	**BLL=8**	**BLL=10**	**Exposure Frequency (day/week)[5]**	**EPC at Residential Yard (mg/kg)**	**BLL=5**	**BLL=8**	**BLL=10**
Set 2a	General Public (High-End Exposure)[1]	12-72 mo.	default (52 - 94)	default (0.43 - 0.60)	Bkgd mean [total] (2.35)	default	30%	178	420	590	1	151[7]	340	2,034	3,224
	Tribal Lifeway (High-End Exposure)[1]	12-72 mo.	RME (400)	RME (0.78)	Bkgd mean [total] (2.35)	All food (100%)[9]	30%	15	60	91	2	151[7]	n/v	n/v	n/v
											5	151[7]	n/v	24	67
Set 2b	Tribal Lifeway (Hybrid Scenario)[2,8]	12-36 mo.	default (52 - 94)	default (0.43 - 0.51)	TWA (1.94)[9]	All Food (25%)[10]	30%	339	913	1,330	5	151[7]	414	1,218	1,802
		36-72 mo.		RME (0.78)											
		12-36 mo.	default (52 - 94)	default (0.43 - 0.51)	TWA (1.94)[9]	All Food (25%)[10]	40%	200	625	933	5	151[7]	220	815	1,246
		36-72 mo.		RME (0.78)											

Notes:

[1] The PRGs calculated for the high-end exposure scenarios for the GP and TLW child (Scenarios 1 and 5 in Table 4, respectively) are refined using the TWA approach.

[2] PRGs are calculated for the CDC's recommended age range (12 to 72 months old).

[3] PRGs obtained directly from the IEUBK model without considering receptors exposure frequency at OU5 (I.e., daily sediment exposure is assumed).

[4] PRGs are presented in the nearest whole number corresponding to each of the target BLLs.

[5] Frequency at which receptors are assumed to visit OU5.

[6] PRGs calculated using the TWA approach, assuming that the receptors visit OU5 at the specified frequency in the table. The receptors are also assumed to be exposed to residential yard soil with the specified lead concentration (151 mg/kg) on the days when they do not visit OU5.

[7] Based on the 95th percentile of the mean lead concentration calculated based on a dataset composed of 233 residences in Quapaw, Oklahoma.

[8] PRGs calculated using the hybrid approach. The younger age children (12-36 months old) are assumed to be exposed to lead at their residence only through incidental ingestion of yard soil and drinking water. Lead exposure by the older age children (36-72 months old) is assessed by addressing exposure both at OU5 and their residence using the TWA approach.

[9] The water EPC of 1.94 µg/L is a TWA based on exposure frequency and EPC in each exposure area and is calculated as below. The TWA EPC is used conservatively for both the younger and older age child groups

EPC (1.94 µg/L) = EPC_{RES} (0.9 µg/L; IEUBK default) * (2/7) + EPC_{OU5} (2.35 µg/L bkgd mean [total]) * (5/7).

[10] The PRGs are calculated using the 'Alternate Dietary Value' option, accounting for all food categories sampled from OU5 (i.e., fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant). Lead concentration in meat/fish (total) and vegetables and percentage of food originating from OU5 are entered into the model.

n/v = because of the lead intake through exposure to residential yard soil, no sediment PRG value can be calculated using the IEUBK model (i.e., even if lead concentration in sediment is zero, it would not achieve the target BLL).

Acronyms:
Bkgd = background
BLL = blood lead level
CDC = Centers for Disease Control and Prevention
EPC = exposure point concentration
OU = Operable Unit
PRG = Preliminary Remediation Goal
RME = Reasonable Maximum Exposure
SW = surface water
TWA = time weighted approach

Units
L/day = liters per day
mg/day = milligrams per day
mg/kg = milligrams per kilogram
µg/day = micrograms per day
µg/L = micrograms per liter

Appendix A. Table 6. Estimation of Lead Intake Through Consumption of OU5 Food Items

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Background Data (Biota Samples)

Biota	Number of Results	Number of Detects	FOD	Minimum Non-Detected Concentration (mg/kg)	Maximum Non-Detected Concentration (mg/kg)	Minimum Detected Concentration (mg/kg)	Maximum Detected Concentration (mg/kg)	Average[1] (mg/kg)
Fish (Total)[2]	6	0	0%	0.2317	0.2383	-	-	0.117
Fish (Fillet)[2]	6	0	0%	0.23	0.24	-	-	0.116
Shellfish	28	26	93%	0.24	3.93	0.028	0.14	0.133
Aquatic Reptile/ Amphibian	4	1	25%	0.24	0.24	0.36	0.36	0.180
Semi-Aquatic Mammal	4	0	0%	0.24	0.24	-	-	0.120
Aquatic Plant	1	1	100%	-	-	0.11	0.11	0.110

Background samples were collected from Fourmile Creek (reference watershed).

(1) For non-detected results, one half of detection limit was used to calculate average concentration.

(2) Fish (Total) was used for tribal lifeway exposure scenario, while Fish (Fillet) was used for general public exposure scenario.

Tribal Lifeway Exposure Assumptions

Age Group		Food Consumption Rate (g/day)					References
		Fish (Total)	Shellfish	Aquatic Reptile/ Amphibian	Semi-Aquatic Mammal	Aquatic Plant	
Years	Adult [3]	90	30	24	69	133	Harper (2008)
1-2	Child [4]	31.77	6.38	5.10	21.64	50.01	Estimated based on EPA EFH data (2011, 2018a, 2018b)
2-3		31.77	6.38	5.10	27.73	54.17	
3-4		30.57	8.21	6.57	35.49	65.04	
4-5		30.57	8.21	6.57	35.49	65.04	
5-6		33.80	7.97	6.38	35.49	65.04	

(3) RME food ingestion rates established for tribal lifeway adult based on Harper (2008).

(4) Food consumption rates for child were calculated by multiplying adult food consumption rate by Child/Adult fraction estimated based on EPA EFH and updates (2011, 2018a, 2018b). See Supplemental Table A of Appendix E of the HHRA (CH2M, 2020) for more detailed information.

Age Group	Lead EPC in Food Items[5]	Fish (Total)	Shellfish	Aquatic Reptile/ Amphibian	Semi-Aquatic Mammal	Aquatic Plant	Total Lead Intake (µg/day)
Years	(ug/g)	0.12	0.13	0.18	0.12	0.11	
1-2	Lead Intake (ug/day)	3.72	0.83	0.92	2.60	5.50	13.6
2-3		3.72	0.83	0.92	3.33	5.96	14.8
3-4		3.58	1.07	1.18	4.26	7.15	17.2
4-5		3.58	1.07	1.18	4.26	7.15	17.2
5-6		3.95	1.04	1.15	4.26	7.15	17.6

(5) Average concentrations are used as lead EPCs in food.

Weighted Concentration of Lead in Meat

	Fish	Shellfish	Aquatic Reptile/ Amphibian	Semi-Aquatic Mammal	Sum
Weight[6]	0.42	0.14	0.11	0.32	1.00
Lead EPC * Weight	0.049	0.018	0.020	0.039	
Weighted Average[7]					0.127

(6) Weight is estimated by dividing adult food consumption rate for each food category by a total amount of fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal consumed per day (213 g/day).

(7) Weighted average concentration was calculated as a sum of products of lead EPC and weight for all four food categories.

Acronyms:

EFH = exposure factors handbook
EPA = U.S. Environmental Protection Agency
EPC = exposure point concentration
FOD = frequency of detection
HHRA = human health risk assessment
Max = maximum
Min = minimum
ND = non=detect
OU = Operable Unit
RME = Reasonable Maximum Exposure

Units:

g/day = grams per day
mg/kg = milligrams per kilogram
µg/day = micrograms per day
µg/g = micrograms per gram

References:

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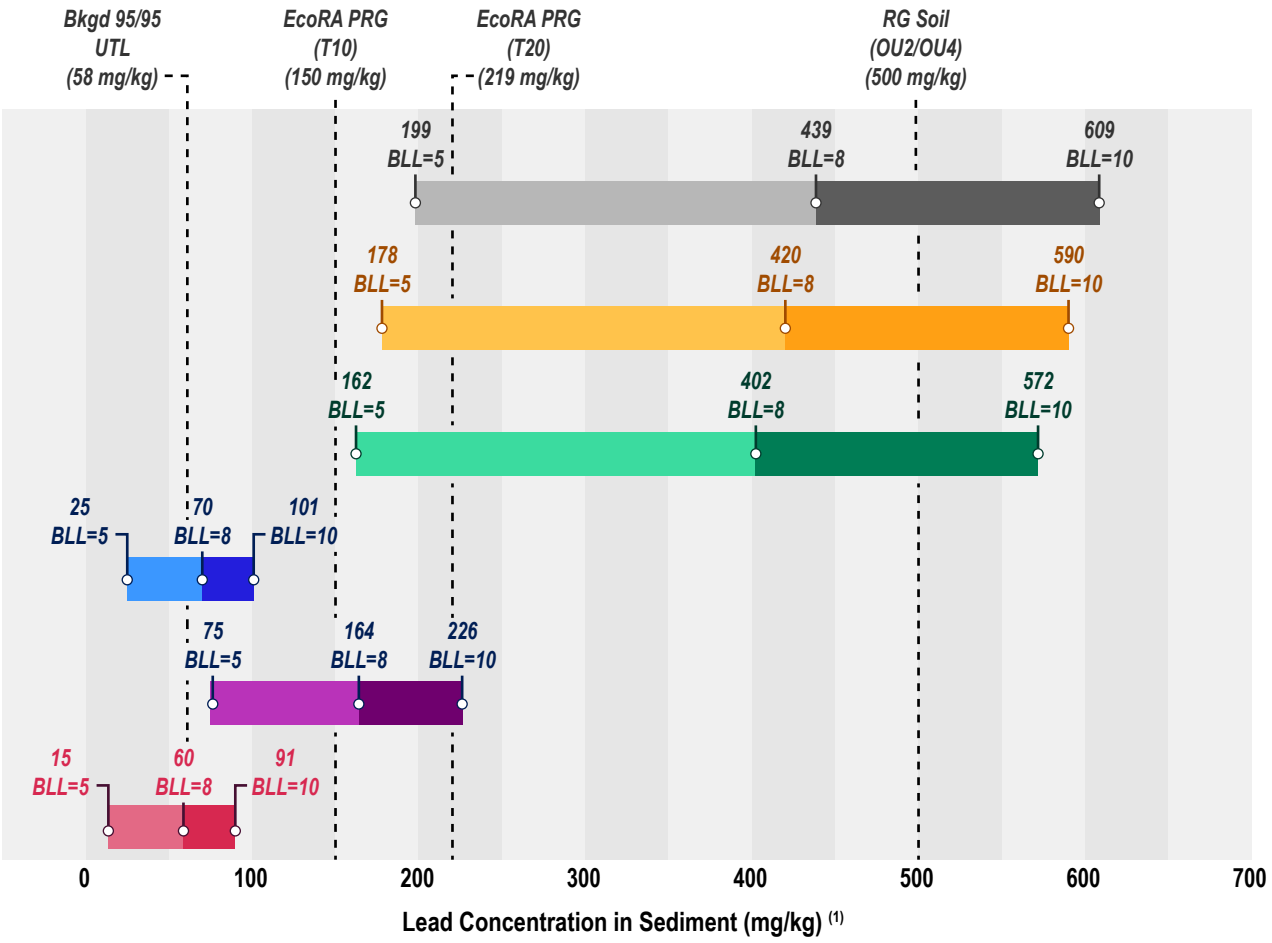
Figures

Appendix A. Figure 1. Lead Estimated PRGs Under Various Scenarios



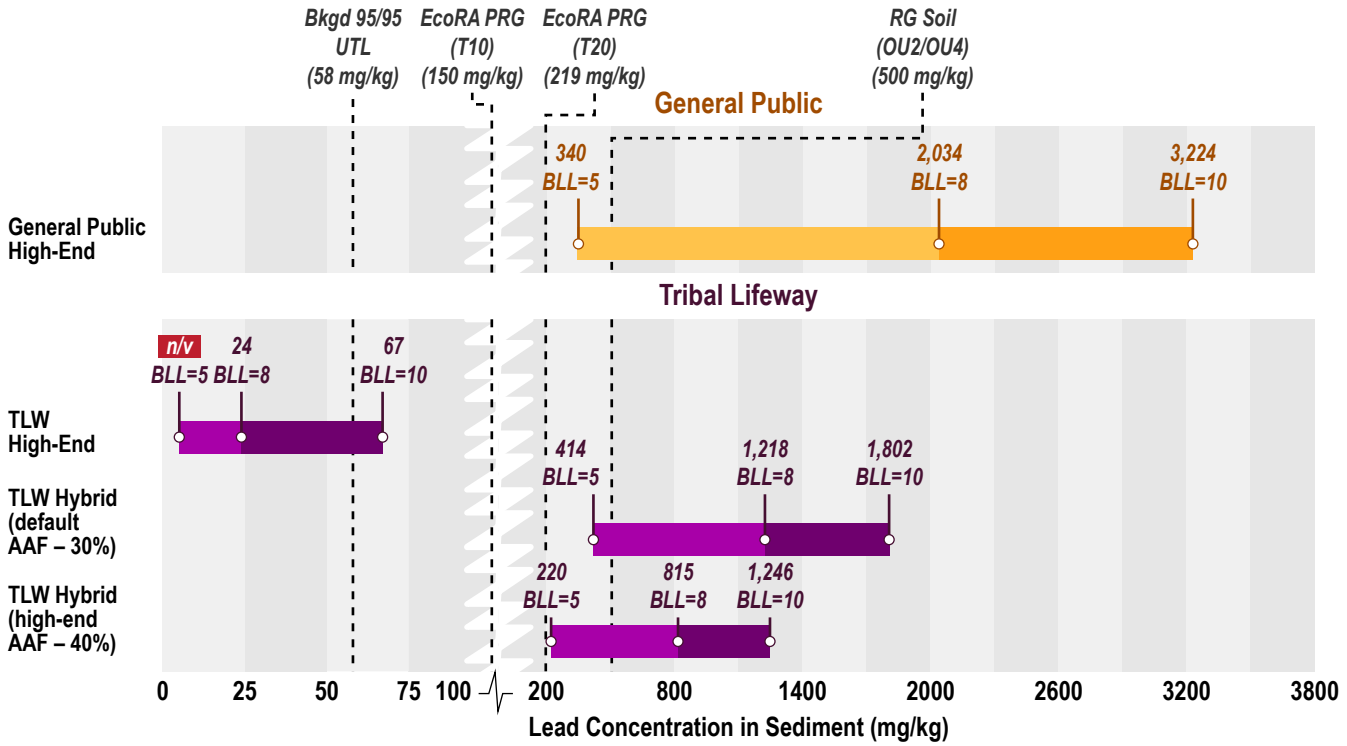
	All Default	Scenario 1 (GP) †	Scenario 2	Scenario 3	Scenario 4	Scenario 5 (TLW) ‡
Sediment IR (mg/day)	default (52–94)	default	default	RME (400)	IR (200)	RME (400)
SW IR (L/day)	default (0.43–0.60)	default	RME (0.78)	RME (0.78)	RME (0.78)	RME (0.78)
SW EPC (µg/L)	default (0.9)	Bkgd mean [total] (2.35)	Bkgd mean [total] (2.35)	Bkgd mean [total] (2.35)	Bkgd mean [total] (2.35)	Bkgd mean [total] (2.35)
Dietary Intake (µg/day)	default (5.03–6.04)	default	default	default	All food (25%)(2)	All food (100%)(2)

mg/kg – milligrams per kilogram mg/day – milligrams per day L/day – liters per day µg/L – micrograms per liter µg/day – micrograms per day

† The scenario corresponds to the high-end exposure scenario evaluated for the GP child in the HHRA.
‡ The scenario closely corresponds to the high-end exposure scenario evaluated for the TLW child in the HHRA.
1. PRGs are calculated for the CDC's recommended age range (12 to 72 months old).
2. Using the 'Alternate Dietary Value' option, accounting for all food categories sampled from OU5 (i.e., fish, shelfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant). Lead concentration in meat/fish (total) and vegetables and specified percentage (25% or 100%) of food originating from OU5 are entered into the model.

Acronyms:
Bkgd - background
BLL - blood lead level
CDC - Center for Disease Control and Prevention
EPC - exposure point concentration
EcoRA - ecological risk assessment
GP - general public
IR - ingestion rate
OU - operable unit
PRG - preliminary remediation goal
RG - remedial goal
RME - Reasonable Maximum Exposure
SW - surface water
T10 - Site-specific toxicity threshold corresponding to 10% reduction in survival or biomass
T20 - Site-specific toxicity threshold corresponding to 20% reduction in survival or biomass
TLW - tribal lifeway
UTL - upper tolerance limit

Appendix A. Figure 2. Estimated PRGs Using Time Weighted Average Approach



	General Public (High-End) [1]		Tribal Lifeway (High-End) [1]		Tribal Lifeway (Hybrid) [2,6,7]		
Age Group	12–72 mo. [2]		12–72 mo. [2]		12–36 mo. [6]	36–72 mo. [7]	
Exposure Area	OU5	Residence	OU5	Residence	Residence	OU5	Residence
Exposure Frequency at OU5 (days/week)	1 [3]	6	5 [4]	2	7	5	2
SW Ingestion (L/day)	default (0.43–0.60)		RME (0.78)		default (0.43–0.51)	RME (0.78)	
SW EPC (µg/L)	Bkgd mean [total] (2.35)		Bkgd mean [total] (2.35)		TWA (1.94) [8]		
Soil/Sediment Ingestion (mg/day)	default (52–94)		RME (400)		default (52–94)		
Soil EPC at Residence (mg/kg)	n/a	151 [5]	n/a	151 [5]	151 [5]	n/a	151 [5]
Dietary Intake (µg/day)	default (5.03–6.04)		All food (100%) [9]		All Food (25%) [9]		
Absorption Fraction (soil/dust) (%)	default (30%)		default (30%)		default (30%) and high-end (40%) [10]		

mg/kg – milligrams per kilogram
mg/day – milligrams per day
L/day – liters per day
µg/L – micrograms per liter
µg/day – micrograms per day

Notes:

High-End Exposure Scenario

1. The PRGs calculated for the high-end exposure scenario for the GP and TLW child are refined using the TWA approach.
2. PRGs are calculated for the CDC's recommended age range (12–72 months old).
3. The GP child is assumed to visit OU5 once a week and is expected to be exposed to residential yard soil at the lead EPC of 151 mg/kg on the days when they don't visit OU5.
4. The TLW child is assumed to visit OU5 five days a week and is expected to be exposed to residential yard soil at the lead EPC of 151 mg/kg on the days when they don't visit OU5.
5. Based on the 95th percentile of the mean lead concentration calculated based on a dataset composed of 233 residences in Quapaw, Oklahoma.

Hybrid Exposure Scenario

6. The younger age children (12–36 months old) are assumed to be exposed to lead at their residence only through incidental ingest on of yard soil and drinking water.
7. Lead exposure by the older age children (36–72 months old) is assessed by addressing exposure both at OU5 and their residence using the TWA approach. They are assumed to visit OU5 five days a week.
8. The water EPC of 1.94 µg/L is a TWA based on exposure frequency and EPC in each exposure area.
9. Using the 'Alternate Dietary Value' option, accounting for all food categories sampled from OU5.
10. Additional set of PRGs is calculated using a high-end AAF (soi/dust) of 40%.

n/v – because of the lead intake through exposure to residential yard soil, no sediment PRG value can be calculated using the IEUBK model (i.e., even if lead concentration in sediment is zero, it would not achieve the target BLL).

Acronyms:

AAF - absolute absorption fraction
Bkgd - background
BLL - blood lead level
CDC - Centers for Disease Control and Prevention
EPC - exposure point concentration
EcoRA - ecological risk assessment
GP - general public
n/a - not applicable
n/v - no value
OU - operable unit
PRG - preliminary remediation goal
sed - sediment
SW - surface water
TLW - tribal lifeway
TWA - time weighted average
UTL - upper tolerance limit

Attachment 1
TRW Lead Committee Review Comments

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

Technical Review Workgroup Lead Committee

An interoffice workgroup convened by Office of Superfund Remediation and Technology Innovation

MEMORANDUM

Date: November 20, 2020

Subject: TRW Lead Committee Consultation: Review of Tar Creek Superfund Site Operable Unit 5 Ottawa County, Oklahoma

From: Matt Lambert (acting), Sophia Serda, and James Brown
Co-Chairpersons of the Technical Review Workgroup Lead Committee

To: Katrina Coltrain, US EPA Region 6

The Technical Review Workgroup (TRW) Lead Committee prepared this memorandum in response to your request on October 14, 2020 for review of Tar Creek Superfund Site Operable Unit 5. As part of this review, the Lead Committee reviewed the 3 exposure scenarios and invited Region 6 to participate in the November 12 monthly teleconference to discuss the site.[1]

TRW Lead Committee has prepared the following responses to questions in your October 14 Consultation Memo (hereafter PDF):

1. *Is there precedence for using the IEUBK model for deriving a lead PRG based on sediment exposure at other Superfund sites? If so, did the PRG consider potential concomitant exposures from other media like water, soil, or biota? In general, our experience is that sediment actions are driven by ecological receptors.*

Yes, and yes. Other sites have used the IEUBK model to derive preliminary remediation goals (PRGs) for lead in sediment (e.g., Cherokee County OU2 Upper Spring River Human Health Risk Assessment [HHRA], Coeur d'Alene HHRA, and Upper Columbia River HHRA). In Region 10, the Coeur d'Alene and Upper Columbia River assessments modeled intermittent exposure to sediments via ingestion from direct contact in recreational or residential areas. Sediment PRGs for children and eco-receptors (swans)

MEMBERS OF THE LEAD COMMITTEE

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*Chair of the Lead Committee

[1] Technical support for this review was provided by SRC, Inc.

were similar at 700 and 520 mg/kg, respectively. In some cases, the PRG reflected exposure to other site related media (incidental ingestion of surface water is common with the sediment exposure pathway). As discussed on the November 12 Lead Committee teleconference, EPA Regions define sediment differently. Because of these differences, which may impact how it should be assessed in risk assessments, this decision is left to Region 6.

2. *For an investigation of one OU at a large environmental remediation site such as Tar Creek Superfund site, could the lead analysis using the IEUBK model focus only on the exposure media associated with the specific OU without considering exposure from other OUs or background lead exposure through typical diet in the United States (the approach used for Set 2 PRGs)?*

No, at this time, lead risk assessment policy calls for all media for which there is a complete exposure pathway to be assessed in the HHRA. The purpose of the IEUBK model is to:

- estimate a blood lead level for a human child receptor
- estimate a risk of exceeding a specified target blood lead level (BLL) for a given exposure scenario
- estimate a PRG, from a set of exposures at the specified target BLL

The IEUBK sums all sources of exposure to estimate blood lead levels. As a biomarker of exposure, blood lead does not simulate "source apportionment". This is the meaning of "Integrated" in the IEUBK model. Unavoidable sources of exposure are typically included in background levels of lead in air, water, and diet. While potentially cumbersome, it may be useful to estimate risks for each of these approaches (sets), and for each approach that results in unacceptable risks, calculate scenario specific PRGs. Across OUs, one may consider the PRG for the residential OU as the *home soil* exposure point concentration (EPC) in the time-weighted average (TWA) calculation for the non-residential OU risk calculations. Then use risk management to select a PRG for Lead (and possibly other chemicals of concern) in each OU5 media.

3. *Given the finding that all the scenarios using a sediment ingestion rate of 400 mg/day yield a PRG lower than the lead Background Threshold Value (BTW) of 59 mg/kg, what does the TRW Lead Committee recommend for handling exposures specific to a Tribal Lifeway (TLW) receptor for their future potential beneficial use of their lands (knowing that the IEUBK model was not developed for subsistence TLW high exposure levels)? That is, if we cannot use the IEUBK lead model to develop PRGs for a TLW exposure scenario, what other tools are available to evaluate such exposures?*

The TRW Lead Committee made the following recommendation regarding the soil ingestion rate in their December 2019 Tar Creek review:

> "For Model Run 2, the selected ingestion rate of 400 mg/day for sediment seems very high compared to what is typically used for children (generally 100 mg/day or less). Central tendency estimates are recommended for lead risk assessment."

Because of the way the EPA Lead models use statistical parameters to calculate an upper bound exposure, BLL, and PRG, central tendency values should be used for inputs in the IEUBK and Adult Lead Methodology (ALM). The TRW Lead Committee does not consider 400 mg/day to be a central tendency soil-dust ingestion rate (IR) for a human child receptor. Because the IEUBK model estimates exposure over months, the current IRs should be considered in

conjunction with time weighted averaging to estimate the impact of sediment. A Harper (2008) report is cited in the PDF as the basis for using an IR of 400 mg/day, which comes from Harper et al. (2007). The Harper et al. (2007) soil IRs are outdated. The 400 mg/day for soil (i.e., not dust) relies in large part on the U.S. EPA's 1997 Exposure Factors Handbook (EFH) Table 4-23 upper percentile (i.e., defined as 95th percentile, not undefined as suggested by Harper on p. 259 of that 2007 report). However, the 1997 EFH footnoted the 400 mg/day for soil with "Study period was short; therefore, these values are not estimates of usual intake." Irvine et al. (2014) reported a 95th percentile IR of 361 mg/day for soil IR but stated, "… the mean as well as the 95th percentile estimates [determined by Irvine et al.] lower than Harper et al.'s (2007) prediction of soil ingestion rates for First Nations people (i.e. 400 mg/day)." Harper et al. (2007) did not actually provide a prediction of 400 mg/day IR for soil, but rather relied in large part on the EPA's 1997 EFH Table 4-23 upper percentile.

There are two relatively small studies (Irvine et al., 2014; Doyle et al., 2012) of tribal adults (16 subjects in total) practicing tribal lifestyles for short periods of time (in one case, 2 weeks). The most reliable tracers estimated that mean soil ingestion was 32 to 74 mg/day. If reasonable maximum exposure (RME) values (e.g., 200 mg/day) are used to represent a child's mean soil IR, this should be discussed in the uncertainty section of the risk assessment.

The TRW believes that the IEUBK model is a reasonable tool for assessing the risk to tribal children. See Question 6 below for a discussion of exposure scenarios and associated PRGs. It is the Superfund program's policy to select background as a cleanup level where the risk-based PRG is below background levels (US EPA, 2002).

4. *Given the finding that no sediment PRG value can be calculated for the TLW child when using the Time Weighted Average (TWA) approach to include added soil exposure from residential properties, does the TRW recommend that the PRG focus only on the exposure media associated with OU5?*

We recommend using the current IEUBK intermittent exposure guidance (U.S. EPA, 2003). The All Ages Lead Model (AALM) could be run to support a sensitivity analysis consistent with what was done on the R10 Upper Columbia River HHRA to better quantify uncertainty, but the AALM is currently being revised to reflect a recent EPA Scientific Advisory Board review. One approach may be to use the relative bioavailability (RBA)-adjusted PRG for the residential OU as the PRG for the sediment (so that a child's recreational exposure is no greater than the residential exposure). Also, by reducing the soil IR the results of some of the alternatives may be above background.

5. *What does the TRW Lead Committee recommend for addressing intermittent lead exposure to sediment or surface water occurring a part of the day or week (knowing that the IEUBK model was developed for continuous residential lead exposure for general public)?*

For an intermittent exposure, the portion of the total exposure frequency (EF) (i.e., days per week, days per year, etc.) that would occur for OU5 media should be determined. For the remaining portion of the total EF, the lead EPC would be based on the receptor's non-site soil lead concentration (e.g., residence, child care facility, schoolyard, etc.), to arrive at a TWA soil (or sediment) lead concentration. The OU5 PRG can then be calculated by knowing what the PRG is for the total receptor exposure and what the lead concentration is in the non-site soil. The TRW Lead Committee recommends using a TWA approach with a soil IR <400 mg/day. The

intermittent exposure guidance (U.S. EPA, 2003) provides recommendations for assessing intermittent or variable exposures at lead sites, including sediment exposure scenarios. The Lead Committee does not usually subdivide a day of exposure for lead risk assessment. If subdividing a day is necessary, it could be considered as an acute exposure.

6. *Which of the 3 sets and/or IEUBK iteration(s) depicted in Figures 1 through 3 is the preferable or recommended approach for identifying the site specific PRG for lead in sediment?*

The TRW Lead committee recommends either using all 3 sets of exposure options to calculate a range of PRGs, or using only set 3b (hybrid scenario with TWA as described on page 9 of the PDF) as the best option since it considers all sources of exposure, while at the same time using a lower soil ingestion rate and TWA strategy to address residential soil exposure. Note that option 3b results in a sediment PRG that is above background levels and reflects risk using appropriate exposure assumptions. The high PRGs in some scenarios are misleading, potentially making people think that the high levels of lead are safe when no exposures to lead are safe. As discussed on the November 12 Lead Committee teleconference and in response to Question 1 above, EPA Regions define sediment differently and because of these differences the selection of an approach to calculate a PRG is a decision left to Region 6.

Other Comments

The TRW Lead Committee has made comments to the PDF file. The results for the TLW scenario are challenging to replicate based on the information provided. Additional information is recommended for transparency (see Appendix 1). Also, the TRW Lead Committee recommend site sampling should characterize bioavailability in solid media (soil and sediment) using the in vitro bioaccessibility assay (IVBA) (U.S. EPA, 2007).

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Appendix 1. Reproducing the Results

The IEUBK results for the general public (GP) and TLW can be reproduced. The GP results can be readily reproduced based on the text and table; however, the TLW results required some additional effort as described below.

The TLW low-end exposure scenario used default soil intake (where dust lead concentration = 0 ppm) for the three years prior to the 36-72 month age range. Default soil/dust ingestion rates were used for the 0-35 months age range (instead of zero). A PRG of approx. 605 ppm for P5 (compared to 671 ppm if the prior years are zeroed out) and approximately 1400 ppm for the P10 (compared to 1,552 ppm).

If the objective was to set the diet intake equal to zero except for the intake from aquatic plants, entering zero for diet lead intakes does not achieve the intended results. The series of screen captures below compares the diet lead uptake (not intake) for the GP Low-End Exposure (first two images) to the diet lead uptake using the same exposure parameters except the default intakes are entered for diet (images 3-4). Note the diet lead uptakes are the same. This is expected because once the 'Use alternate diet values' option is selected, the code does not use the values for 'Dietary Lead Intake' that appear at the top of the Dietary Data window. The code calculates intakes using the default consumption data and concentration data along with the values for alternate dietary concentration and percent of food class. Only alternate food categories with non-zero percentages are used to calculate the dietary intake. The last two images illustrate this point. Figure 5 effectively shows intake from vegetables, fruits and market meats (which includes fish) was zeroed out by entering 100% for vegetables and fruits (with zero concentration) and entered 75% for game animals from hunting (with zero concentration). Figure 6 shows the diet lead uptakes are now lower than they are in Figures 2 and 4, which correspond to the parameter values shown in Figures 1 and 3. The diet lead uptakes are still not zero because of the other diet categories that are not available to the user (e.g., dairy, bread, pasta).

The resulting P5 and P10 PRGs for soil lead at 15 ppm and 91 ppm (respectively) are shown in Figures 7 and 8, respectively.

Figure 1. diet parameter values corresponding to GP-Low End Exposure.

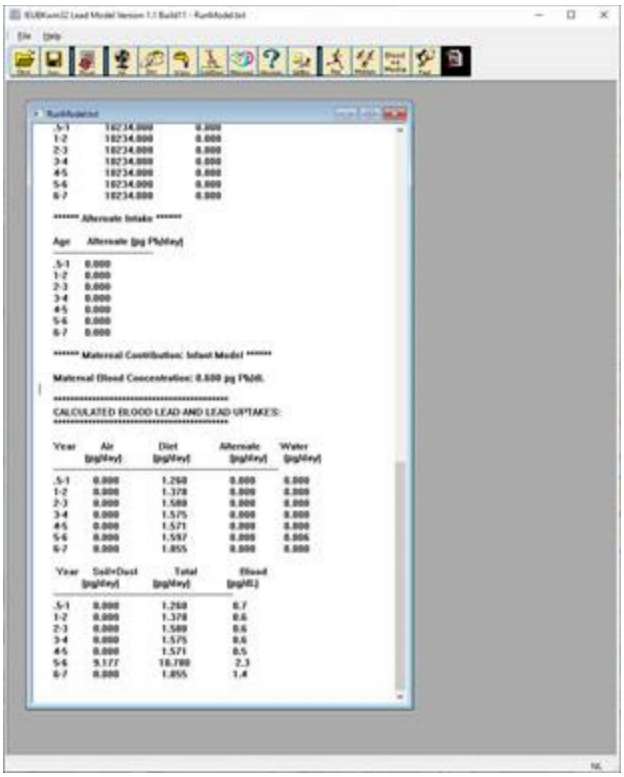


Figure 2. Diet lead uptake corresponding to GP-Low End Exposure.

Figure 3. Diet parameter values with default values in the 'Dietary Lead Intake' instead of zero (compare to Figure 1).

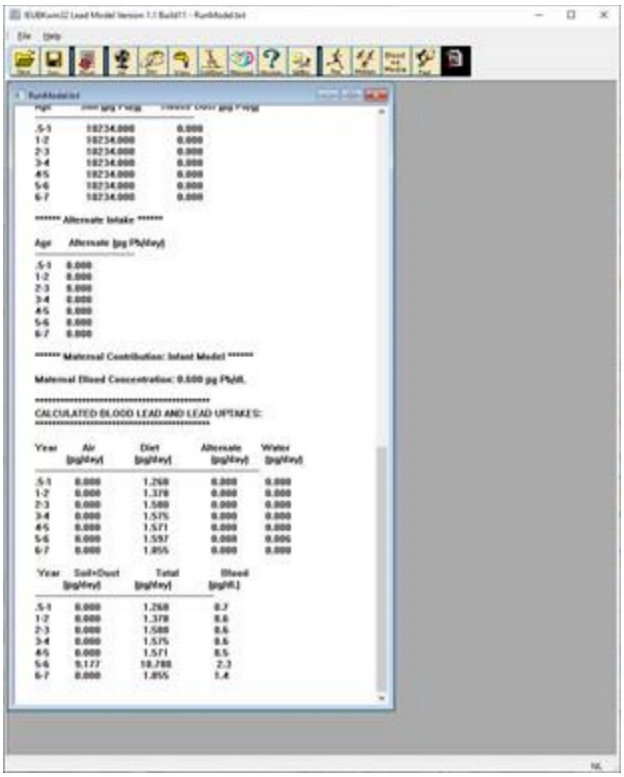


Figure 4. Diet lead uptake corresponding to default values in the 'Dietary Lead Intake' instead of zero (Figure 3). Compare to Figure 2: no change in the diet lead uptake values.

Figure 5. Diet parameter values with default values in the 'Dietary Lead Intake' set to zero – which has no effect on the calculations of lead intake, uptake or BLL because the 'Use alternate dietary values?' button has been selected (set to 'Yes'). The combination of the Percent of Food Class' values and zero concentration for home grown fruits and vegetables effectively sets the intake from total fruits and total vegetables (market and home grown) equal to zero. By setting the percentage of game animals to 75% results in self-caught fish being the only lead intake from meats. Market meats (fish and non-fish) and game animals contribute zero lead intake (compare to Figures 1 and 3).

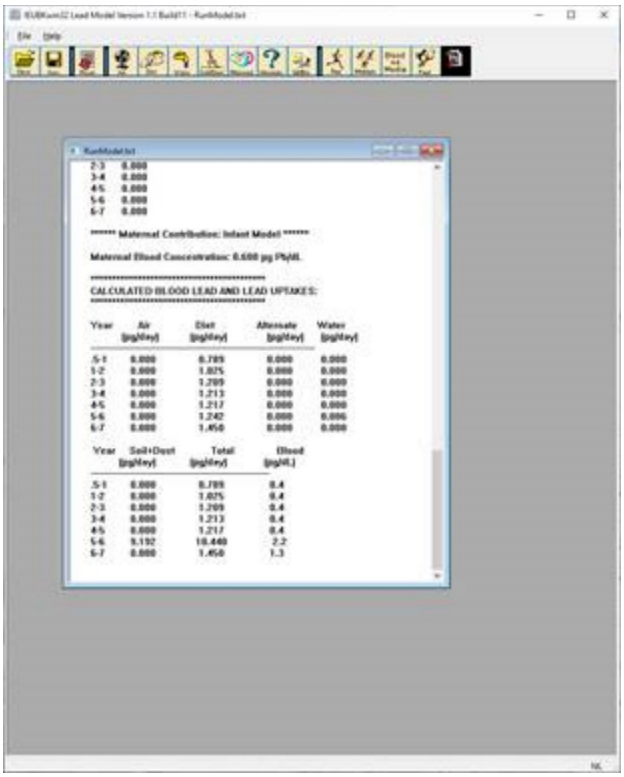


Figure 6. Diet lead uptake corresponding to parameter values shown in Figure 5, which shows lead intake/uptake from home grown fruits and vegetables, and game animals set to zero. Compare to Figure 6 to Figures 2 and 4. Dietary lead uptake is lower but not zero due to lead intake from other diet categories that are not available to the user (e.g., dairy).

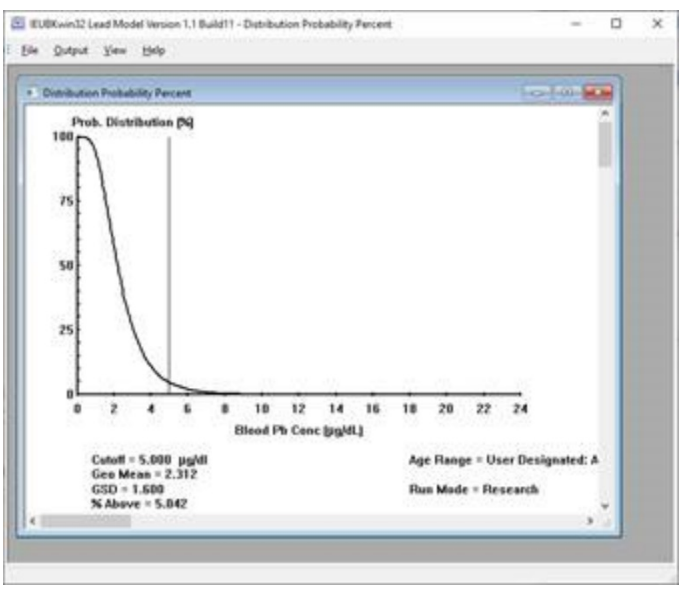


Figure 7. Calculated PRG for the P5 TLW-high, using the svd file for TLW-high with soil = 15 ppm.

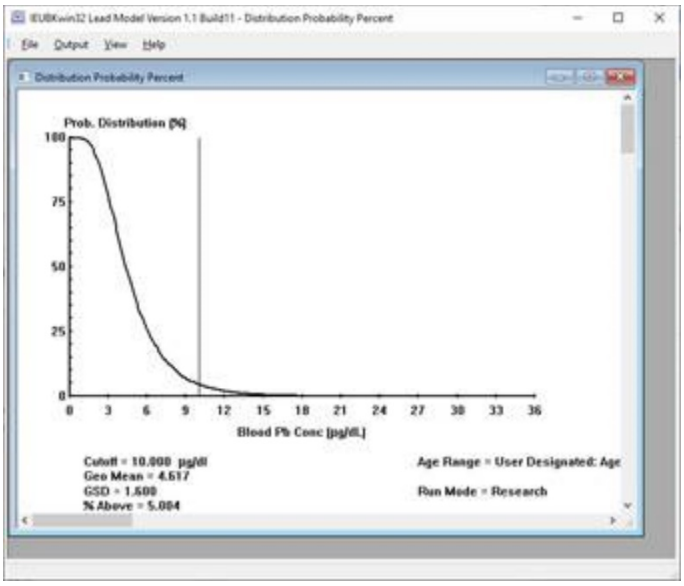


Figure 8. Calculated PRG for the P10 TLW-high, using the svd file for TLW-high with soil = 91 ppm.

Attachment 2
Sensitivity Analysis of Key Input Parameter Values in the Integrated Exposure Uptake Biokinetic (IEUBK) Model

Attachment 2

Sensitivity Analysis of the Key Input Parameter Values in the Integrated Exposure Uptake Biokinetic (IEUBK) Model

Approach

To assess the sensitivity of key input variables, a preliminary assessment of sediment preliminary remediation goals (PRGs) was performed for each of the three key exposure pathways (sediment ingestion, surface water ingestion, and food consumption [i.e., dietary intake]). Table 3 of the Detailed Lead PRG Methodology, summarizes key input variables and values that are assessed. In this analysis, sediment exposure is simply treated as soil exposure and surface water exposure is treated as drinking water in the model, and the calculated soil PRGs are presented as sediment PRGs. As such, it is assumed that Operable Unit 5 (OU5) sediments are brought home and children are exposed to sediment at home in the form of dust ingestion and that they are exposed to lead in indoor and outdoor air originating from a non-OU5-related source. In this analysis, to expedite the calculation process, PRGs are calculated for the age group 12 to 84 months old, an age group closely encompassing the age group of our interest (12 to 72 months old) (EPA, 2017), among the age group options available in the IEUBK's “Find” function.

Brief descriptions of input parameter values are presented below.

Sediment Ingestion

- Sediment ingestion rate was incrementally increased from the default values (ranging from 52 to 94 milligrams per day [mg/day] for various age groups) to 100, 200, 300, and up to 400 mg/day (i.e., the reasonable maximum exposure [RME] sediment ingestion rate identified based on Harper [2008]). For the scenario using the RME sediment ingestion rate of 400 mg/day, two additional scenarios incorporating a reduced absorption fraction of soil/dust (from the default value of 30% to 25% and 20%) were evaluated to see if they would change the PRG values.

Surface Water Ingestion

- Surface water ingestion rate and exposure point concentration (EPC) are the two input variables determining lead intake through surface water ingestion. The model was run using an RME surface water ingestion rate of 0.78 liter per day, the U.S Environmental Protection Agency’s (EPA’s) RME default drinking water ingestion rate (EPA, 2014). This conservative surface water ingestion rate is assumed to account for three tribal lifeway exposure pathways: (1) incidental ingestion through hunting/fishing/gathering and recreational activities, (2) ingestion of surface water as a drinking water source, and (3) ingestion of surface water during sweat lodge use. The background mean lead concentration (2.35 micrograms per liter) is used as the EPC in surface water. Due to the lack of media transfer information between sediment and surface water, it is assumed that surface water concentrations (for lead) will be comparable to background following sediment remediation.

Dietary Lead Intake

- Dietary lead intake is estimated using two approaches.
  - In the first approach, dietary lead intake was calculated based on the RME food ingestion rates used in the Human Health Risk Assessment (CH2M, 2020) and mean background concentrations. The RME food ingestion rates were estimated based on adult food ingestion rates identified in Harper (2008) and child/adult ingestion rate ratios identified for the major food groups in the EPA's Exposure Factors Handbook (2011, 2018a, 2018b) presented in Table 6 of the Detailed Lead PRG Methodology.
  - The second approach uses the "Alternate Dietary Value" option in the IEUBK model, and lead concentration and percentage of food originating from OU5 are entered as input into the model.
- Due to the lack of media transfer information between sediment and biota, it is assumed that biota concentrations (for lead) will be comparable to background following remediation of sediment. For the scenario assessing dietary lead intake from fish ingestion for the general public children, the background mean concentration of fish (fillet) (0.116 milligram per kilogram [mg/kg]) is used. For the tribal lifeway scenario addressing dietary lead intake from all food categories sampled from OU5 (fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal), a weighted average of lead concentration was calculated based on the adult ingestion rate of each food category (Table 6 of the Detailed Lead PRG Methodology).
- Additionally, the sediment PRGs are calculated for three additional scenarios using various combinations of exposure assumptions to yield the higher end of the potential PRG range.

Dust Ingestion and Outdoor/Indoor Air Exposure

Lead exposure through dust ingestion is evaluated using the IEUBK's Multiple Source Analysis function, and inhalation of lead in indoor and outdoor air is evaluated using the IEUBK's default setting (i.e., outdoor air lead concentration of 0.1 microgram per cubic meter and indoor air lead concentration is 30% of outdoor air lead concentration).

Findings

The results of each set of the IEUBK model runs are summarized and shown in the attached Table 1 and Figure 1. Findings of the sensitivity analysis are summarized below.

- Among the input variables, sediment ingestion rate is the most influential parameter on the sediment PRG. The scenario using a sediment ingestion rate of 200 mg/day calculated a sediment PRG (70 mg/kg) slightly above the lead background threshold value of 59 mg/kg. For the scenario using a sediment ingestion rate of 400 mg/day, a reduced soil/dust absorption fraction does not noticeably change the sediment PRG.
- Surface water EPC and ingestion rate are not as influential as sediment ingestion rate.
- The scenario using the first approach of estimating dietary lead intake was not able to calculate a sediment PRG for a target blood lead level of 5 micrograms per deciliter (µg/dL) because of the significant contribution of lead intake from food consumption. In other words, even if the lead concentration in sediment is zero, the percentage of children with a blood lead level exceeding the target of 5 µg/dL is more than 5%.
- When dietary lead intake through fish consumption is entered, the model using the alternate dietary value option (the second option above), the model estimated a higher sediment PRG than the scenario using the default dietary intake values.

References

CH2M. 2020. *Tar Creek Superfund Site Operable Unit 5. Ottawa County, Oklahoma. Human Health Risk Assessment. DCN: 0079-02017.* May.

EPA. 2011. *Exposure Factors Handbook: 2011 Edition.* National Center for Environmental Assessment, Office of Research and Development. EPA/600/R-09/052F. September.

EPA. 2014. *Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors.* OSWER Directive 9200.1-120. February 6

EPA. 2017. *Recommendations for Default Age Range In the IEUBK Model.* Office of Land and Emergency Management (OLEM) Directive 9200.2-177. November 15.

EPA. 2018a. Update for Chapter 9 of the Exposure Factors Handbook. Intake of Fruits and Vegetables. Table 9-3. EPA/600/R-18/098F. August.

EPA. 2018b. Update for Chapter 11 of the Exposure Factors Handbook. Intake of Meats, Dairy Products, and Fats. Table 11-3. EPA/600/R-17/485F. August

Harper, Barbara. 2008. *Quapaw Traditional Lifeways Scenario.* Prepared by Barbara Harper, PhD, DABT. AESE, Inc.

Table

Attachment 2. Table 1. Sensitivity Analysis of Key Input Parameter Values

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Medium/Exposure Pathway	Age Group[a]	Soil/ Sed Ingestion (mg/day)	SW Ingestion (L/day)	SW EPC (µg/L)	Dietary Intake (µg/day)	Absorption Fraction (percent)	Estimated PRGs		
							BLL=5	BLL=8	BLL=10
All Default	12-84 mo.	Default (52-94)	Default (0.43 - 0.63)	Default (0.9)	Default (5.03 – 6.04)	Default (30%)	216	474	656
Soil/Sediment	12-84 mo.	100	Default	Default	Default	Default	147	325	450
	12-84 mo.	200	Default	Default	Default	Default	70	159	221
	12-84 mo.	300	Default	Default	Default	Default	44	104	145
	12-84 mo.	400	Default	Default	Default	Default	32	76	107
	12-84 mo.	400	Default	Default	Default	25%	39	93	130
	12-84 mo.	400	Default	Default	Default	20%	51	118	164
SW	12-84 mo.	Default	Default	Bkgd mean [dissolved] (1.63)	Default	Default	205	463	644
	12-84 mo.	Default	Default	Bkgd mean [total] (2.35)	Default	Default	194	452	633
	12-84 mo.	Default	0.78	Bkgd mean [total] (2.35)	Default	Default	177	435	616
Diet	12-84 mo.	Default	Default	Default	Fish (25%)[b]	Default	279	538	720
	12-84 mo.	Default	Default	Default	All food (25%)[c]	Default	272	530	713
	12-84 mo.	Default	Default	Default	All food (100%)[c]	Default	155	412	594
	12-84 mo.	Default	Default	Default	13.6 – 17.6[d]	Default	n/v	180	360
Combined Scenario 1	12-84 mo.	Default	Default	Bkgd mean [total] (2.35)	Fish (25%)[b]	Default	257	516	698
Combined Scenario 2	12-84 mo.	400	0.78	Bkgd mean [total] (2.35)	Default	Default	25	69	100
Combined Scenario 3	12-84 mo.	400	0.78	Bkgd mean [total] (2.35)	All food (100%)[c]	Default	14	59	90

Notes:

[a] To expedite the calculation process, PRGs are calculated for age group 12-84 months old, because among the available age groups in the IEUBK's "Find" function, this age group closely represents age group of our interest (i.e., 12-72 months old, the CDC's recommended age range).

[b] The PRGs are calculated using the "Alternate Dietary Values" option and entering lead concentration in fish (fillet) and percentage of fish originating from OU5. The average lead concentration in background fish fillet samples (0.116 µg/g) are used in the calculations (see Table 6).

[c] The PRGs are calculated using the "Alternate Dietary Values" option, accounting for all food categories sampled from OU5 (i.e., fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant). Lead concentration in meat/fish (total) and vegetables and percentage of food originating from OU5 are entered into the model. The weighted average lead concentration in meat/fish (0.127 µg/g) and vegetables (0.11 µg/g) in background samples are used in the calculations (see Table 6).

[d] The PRGs are calculated entering dietary lead intake values calculated based on background mean concentrations and RME ingestion rates (see Table 6).

n/v = because of the lead intake through dietary intake, no sediment PRG value can be calculated using the IEUBK model (i.e., even if lead concentration in sediment is zero, it would not achieve the target BLL).

Acronyms:
Bkgd = background
BLL = blood lead level
CDC = Centers for Disease Control and Prevention
IEUBK = Integrated Exposure Uptake Biokinetic (model)
mo. = months
n/v = no value
OU = Operable Unit
PRG = preliminary remediation goal

Units
L/day = liters per day
mg/day = milligrams per day
µg/day = micrograms per day
µg/g = micrograms per gram
µg/L = micrograms per liter

Figure

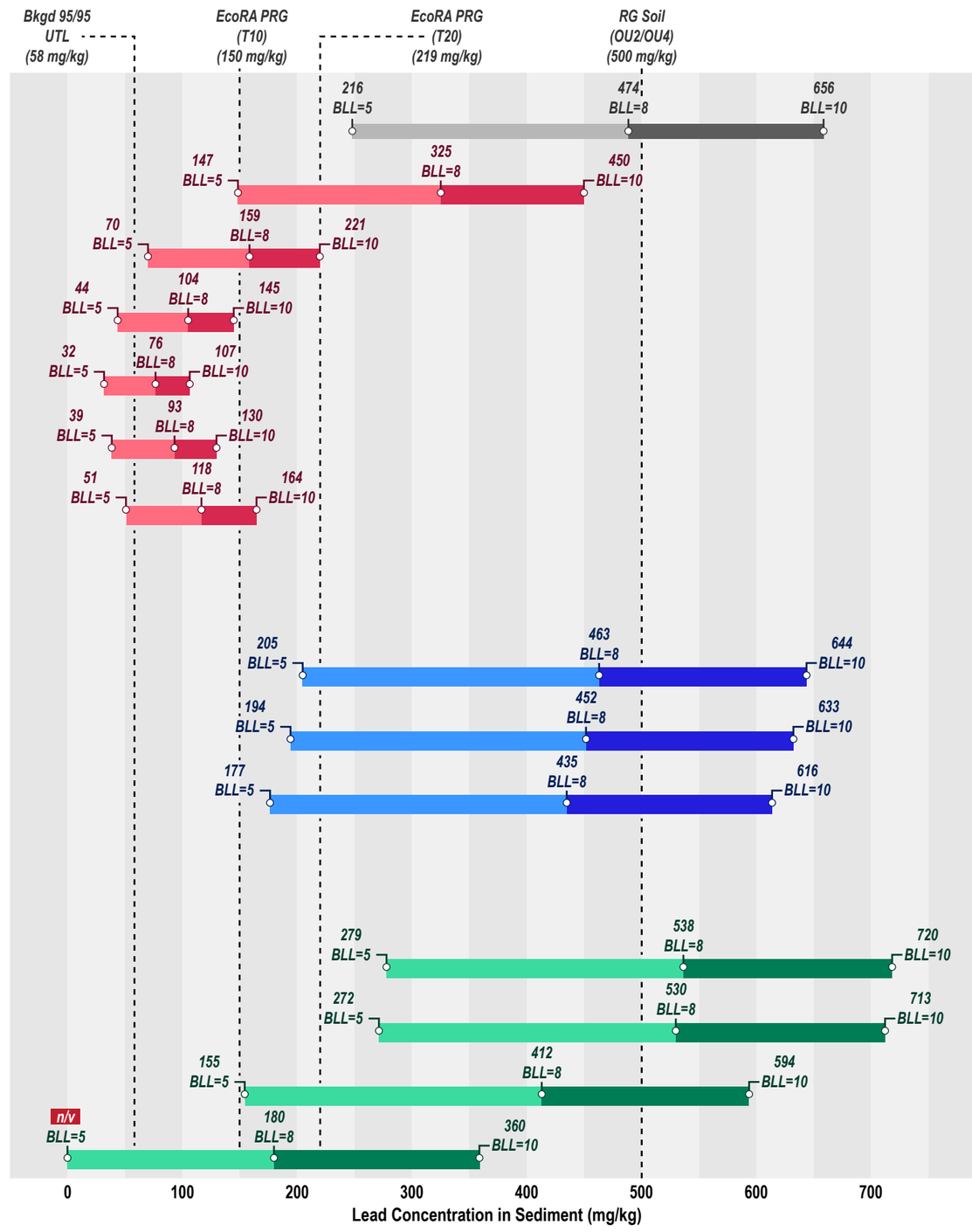
Attachment 2. Figure 1. Sensitivity Analysis of Key Input Parameter Values[1)(2)]

Medium/Exposure Pathway	Soil/Sed Ingestion (mg/day)	Absorption Fraction (percent)
All Default	default (52-94)	default (30%)
Soil/Sediment	100	default
	200	default
	300	default
	RME (400)	default
	RME (400)	25%
	RME (400)	20%

Medium/Exposure Pathway	SW Ingestion (L/day)	SW EPC (µg/L)
All Default	default (52-94)	default (0.9)
SW	default	Bkgd mean [dissolved] (1.63)
	default	Bkgd mean [total] (2.35)
	RME (0.78)	Bkgd mean [total] (2.35)

Medium/Exposure Pathway	Dietary Intake (µg/day)
All Default	default (5.03 – 6.04)
Diet	Fish (25%)[3a)]
	All Food (25%)[3b)]
	All Food (100%)[3b)]
	13.6 – 17.6[4)]

mg/kg – milligrams per kilogram
mg/day – milligrams per day
L/day – liters per day
µg/L – micrograms per liter
µg/day – micrograms per day
µg/g – micrograms per gram



Notes:

1. PRGs are calculated for age group 12-84 months old.

2. The input parameter values other than those presented in the left of the graph are set at the IEUBK model's default values.

3. The 'Alternate Dietary Value' option was used.

a. The average lead concentration in background fish fillet samples (0.116 ug/g) are used in the calculations.

b. The weighted average lead concentration in meat/fish (0.127 ug/g) and vegetables (0.11 ug/g) in background samples are used in the calculations.

4.The PRGs are calculated entering dietary lead intake values calculated based on background mean concentrations and RME ingestion rates.

n/v - because of the lead intake through dietary intake, no sediment PRG can be calculated (i.e., even if lead concentration in sediment is zero, it would not achieve the target BLL).

Acronyms:
Bkgd - background
BLL - bloood lead level
EPC - exposure point concentration
EcoRA - ecological risk assessment
n/v - no value
PRG - preliminary remediation goal
RME - Reasonable Maximum Exposure
sed - sediment
SW - surface water
UTL - upper tolerance limit

Attachment 3
IEUBK Input Values for PRG Set 2b

Attachment 3. IEUBK Input Values for PRG Set 2b (Hybrid Approach)
Tar Creek Superfund Site Operable Unit 5
Ottawa County, Oklahoma

Soil and Sediment Ingestion:

Site Specific Soil Dust Data

Soil/Dust Ingestion Weighting Factor (percent soil): 45

OK | Cancel | Reset | Help?

Outdoor Soil Lead Concentration (µg/g)
- Constant Value 200
- Variable Values

Indoor Dust Lead Concentration (µg/g)
- Constant Value 200
- Variable Values
- Multiple Source Analysis — Set
- Multiple Source Avg: 190.9

Soil/Indoor Dust Concentration (µg/g)

	AGE (Years) 0-1	1-2	2-3	3-4	4-5	5-6	6-7
Outdoor Soil Lead Levels:	151	151	151	339	339	339	339
Indoor Dust Lead Levels:	115.7	115.7	115.7	247.3	247.3	247.3	247.3

Amount of Soil/Dust Ingested Daily (g/day)

	AGE (Years) 0-1	1-2	2-3	3-4	4-5	5-6	6-7
Total Dust + Soil Intake:	0.086	0.094	0.067	0.063	0.067	0.052	0.055

GI Values/Bioavailability: GI / Bio — Change Values

TRW Homepage: http://www.epa.gov/superfund/health/contaminants/lead/index.htm

Notes:

- The 'Variable Values' option is selected to input different lead concentrations in soil/indoor dust for the younger (0-3 years old) and older children (3-7 years old)
- The EPC (151 mg/kg) in outdoor soil is based on 95th percentile of the mean from 233 residences in Quapaw, Oklahoma.
- Indoor dust lead concentrations are estimated based on outdoor soil lead concentrations and outdoor air lead concentrations using the multiple source analysis.
- The outdoor concentrations for the older age child (3-7 years old) is identified by running the model multiple times. The values are time-weighted values representing the nearest whole number corresponding to 5% above each of the target BLLs.

Outdoor/Indoor Air Inhalation:

Air Data

Indoor air lead concentration (percentage of outdoor): 30

Outdoor Air Pb Concentration (µg/m³):
- Constant Value: 0.1
- Variable Values

OK | Cancel | Reset | Help?

Input for different age groups

	AGE (Years) 0-1	1-2	2-3	3-4	4-5	5-6	6-7
Outdoor Air Pb Concentration (µg/m³):	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Time Spent Outdoors (hr/day):	1	2	3	4	4	4	4
Ventilation Rate (m³/day):	3.22	4.97	6.09	6.95	7.68	8.32	8.89
Lung Absorption (%):	32	32	32	32	32	32	32

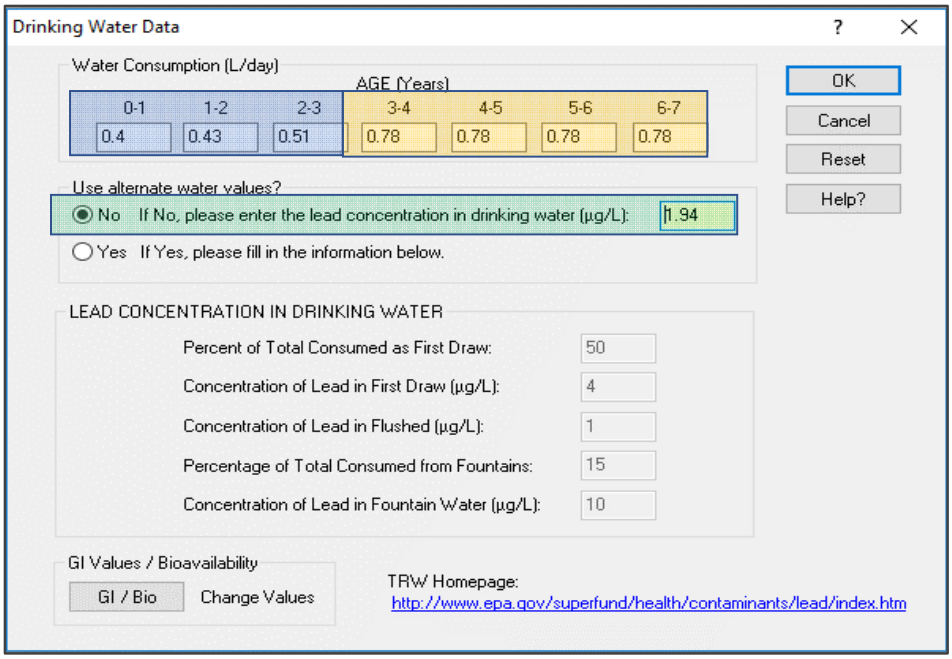
TRW Homepage: http://www.epa.gov/superfund/health/contaminants/lead/index.htm

Note:

- The IEUBK's default values are used in the calculation.

Attachment 3. IEUBK Input Values for PRG Set 2b (Hybrid Approach)
Tar Creek Superfund Site Operable Unit 5
Ottawa County, Oklahoma

Water Ingestion:



Notes:

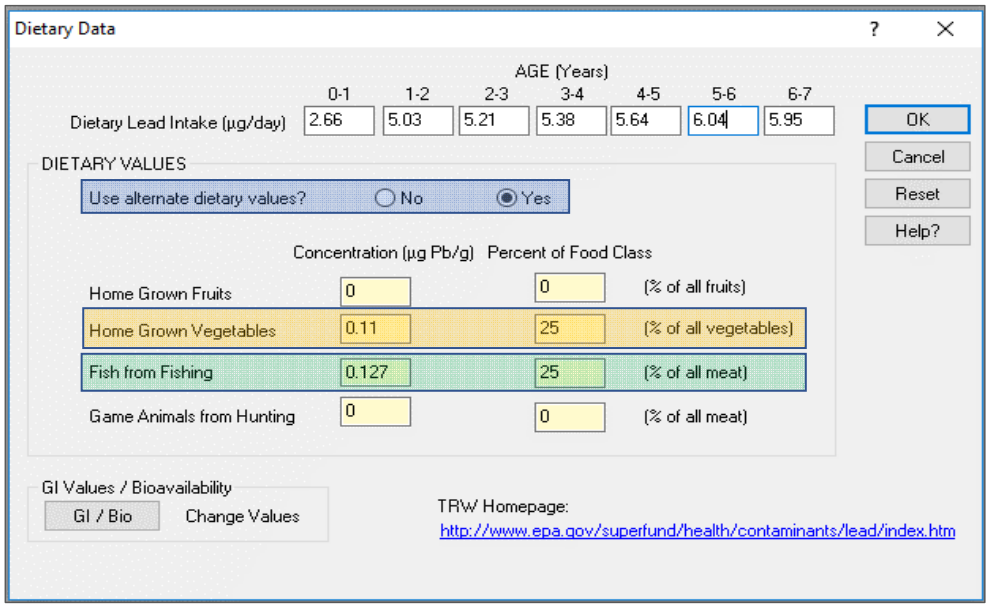
The IEUBK's default water consumption rates are used for the younger child (0-3 years old).

The RME water consumption rate (0.78 L/day; EPA 2014) is used for the older children (3-7 years old).

The water EPC of 1.94 µg/L is a time-weighted average.

EPC (1.94 µg/L) = EPC_{RES} (0.9 µg/L; IEUBK default) * (2/7) + EPC_{OU5} (2.35 µg/L background mean) * (5/7).

Dietary Intake:



Notes:

The PRGs are calculated using the 'Alternate Dietary Value' option, accounting for all food categories sampled from OU5 (i.e., fish, shellfish, aquatic reptile/amphibian, semi-aquatic mammal, and aquatic plant).

The lead concentration in a background aquatic plant sample (0.11 µg/g) is used in the calculations (see Table 6 of the Detailed Lead Preliminary Remediation Goal Methodology). The percentage of vegetable associated with aquatic plants originating from OU5 (25%) is determined based on professional judgement.

The weighted average lead concentration in meat/fish (0.127 µg/g) in background samples is used in the calculations (see Table 6 of the Preliminary Detailed Lead Remediation Goal Methodology). The percentage of meat/fish associated with food originating from OU5 (25%) is determined based on professional judgement.

Appendix B
Sediment and Aquatic Plant Regression Analysis

Appendix B

Sediment and Aquatic Plant Regression Analysis, Tar Creek Superfund Site, Operable Unit 5

During the development of preliminary remediation goals (PRGs), an evaluation of the correlation between the sampled aquatic plants (arrowhead) and their collocated sediment samples was performed. Aquatic plant data were obtained from four collocated sediment/aquatic plant sample locations: one from each of the four watersheds (Elm Creek [EC AR 01], Tar Creek [TC AR 01], Lost Creek [LC AR 01], and Lower Spring River [LS AR 01]) (Table 1). For each arrowhead sample, an attempt was made to collect a sample from three different parts (leaf, root, and tuber) of the arrowhead plant; however, a tuber was developed only in the sample collected in Lost Creek (LC AR 01), where the lowest concentrations of chemicals of concern (COCs) in sediment were observed. Without a sufficient quantity of tuber data, an evaluation was performed to develop a regression equation predicting aquatic plant concentrations from sediment concentrations for two aquatic plant parts (leaf and root).

These evaluations include calculations of the Pearson correlation coefficient (the most widely used measure of paired correlation) and the Spearman correlation coefficient, a nonparametric version (based on ranks) of the Pearson correlation coefficient. Both of these values range from -1 to 1 where 1 represents perfect correlation, -1 represents perfect inverse correlation, and 0 represents no correlation. Another well-known measure of correlation, R^2, was also calculated. This value is merely the square of the Pearson correlation coefficient and thus ranges from 0 to 1, where increasing correlation or inverse correlation is indicated by higher R^2 values.

Review of correlation analysis revealed that the plant data correlates to sediment data very well for all cases (R^2 of 0.91 and above) (Table 2). The calculated measures of correlation are presented in Table 2 with the estimates for the slope and intercept of regression equations and the Pearson and Spearman correlation coefficients; scatter plots are presented on Figure 1.

Among the regression equations established for root and leaf data, the equations developed for root data are selected to estimate the relationship between aquatic plant and sediment concentrations because they predict higher concentrations of COCs in aquatic plant than those based on leaf data (Table 2).

The equations below present the relationships between aquatic plant and sediment.

Cadmium: $Aquatic\ Plant\ Conc. = Sediment\ Conc. \times Slope\ (0.136) + Intercept\ (-1.64)$

Zinc: $Aquatic\ Plant\ Conc. = Sediment\ Conc. \times Slope\ (0.120) + Intercept\ (-194.3)$

Appendix B. Table 1. Summary of Analytical Data for Collocated Sediment and Arrowhead Samples

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Chemical of Concern	Medium	Plant Part	Watershed				BTV (Sediment, unsieved)
			Elm Creek	Tar Creek	Lost Creek	Lower Spring River	
Lead	Sediment (unsieved)[a]	n/a	15,700	199	23.5	236	58.4
	Aquatic Plant	Root	838	2.5	1.2	12.1	n/a
		Leaf	304	1.6	0.93	3.1	
		Tuber[b]	n/s	n/s	0.43	n/s	
Cadmium	Sediment (unsieved)[a]	n/a	160	13.9	0.080	52.6	0.7
	Aquatic Plant	Root	21.2	0.73	0.21	2.13	n/a
		Leaf	6.6	0.20	0.21	0.26	
		Tuber[b]	n/s	n/s	0.05	n/s	
Zinc	Sediment (unsieved)[a]	n/a	16,400	3,810	141	5,210	534
	Aquatic Plant	Root	1,840	51.1	30.7	366	n/a
		Leaf	793	46.9	25.2	132	
		Tuber[b]	n/s	n/s	17.5	n/s	

Notes:

[a] All sediment samples were collected from the 0- to 6-inch interval except the sample collected from Elm Creek, which was collected from the 3- to 6-inch interval.

[b] Tuber was not developed in the samples collected from Elm Creek, Tar Creek, and Lower Spring River.

Units are presented in mg/kg on a dry weight basis for sediment and a wet weight basis for aquatic plant.

COCs were detected in all of the sediment and aquatic plant samples, except cadmium in Lost Creek sediment.

Acronyms:

BTV = background threshold value

n/a = not applicable

n/s = not sampled

Units:

mg/kg = milligrams per kilogram

Appendix B. Table 2. Summary Statistics for Regression Models

Tar Creek Superfund Site Operable Unit 5

Ottawa County, Oklahoma

Chemical of Concern	Plant Part	Intercept	Slope	Pearson Correlation Coefficient	R squared	Spearman Correlation Coefficient
Lead	Root	-2.92	0.054	1.00	1.00	1.00
	Leaf	-1.09	0.019	1.00	1.00	1.00
Cadmium	Root	-1.64	0.136	0.97	0.95	1.00
	Leaf	-0.56	0.042	0.95	0.91	0.80
Zinc	Root	-194.29	0.120	0.98	0.96	1.00
	Leaf	-76.25	0.051	0.98	0.95	1.00

Notes:

Regression equation: Concentration in Aquatic Plan (mg/kg[w]) = Slope * Concentration in Sediment (mg/kg[d]) + Intercept.

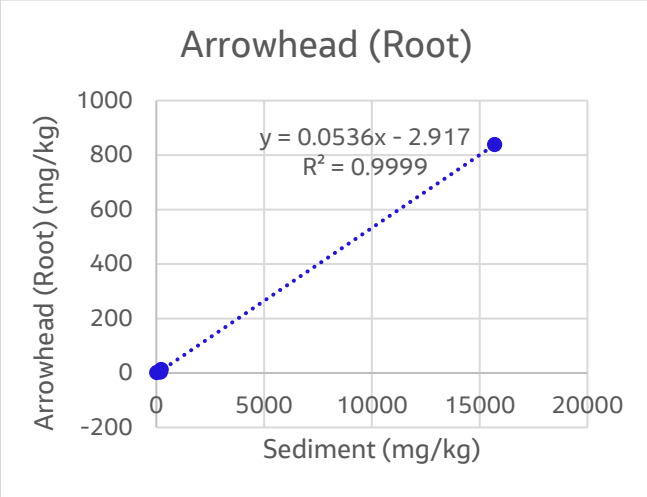
Units

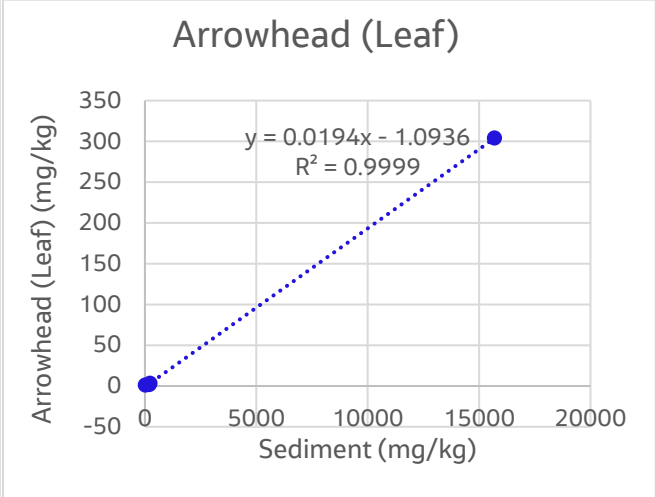
mg/kg[d] = milligrams per kilogram on a dry weight basis

mg/kg[w] = milligrams per kilogram on a wet weight basis

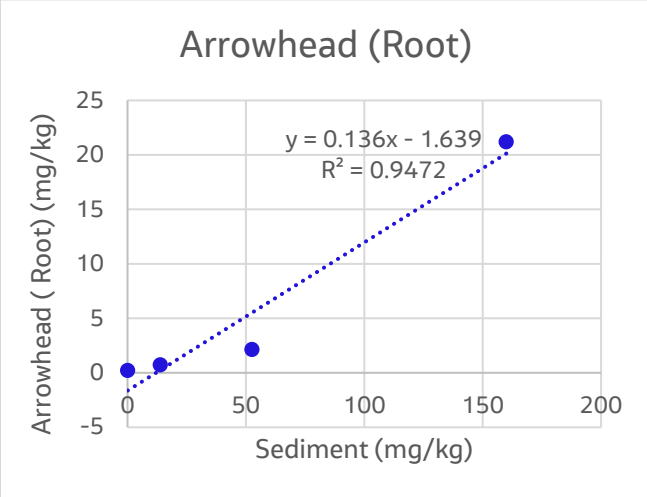
Attachment B. Figure 1. Scatter Plots

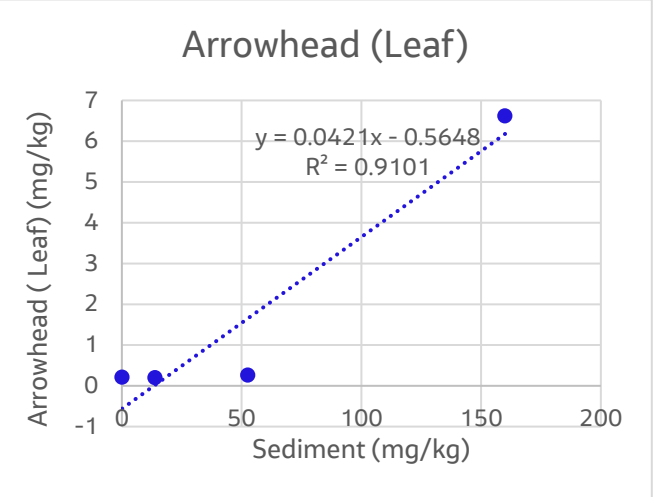
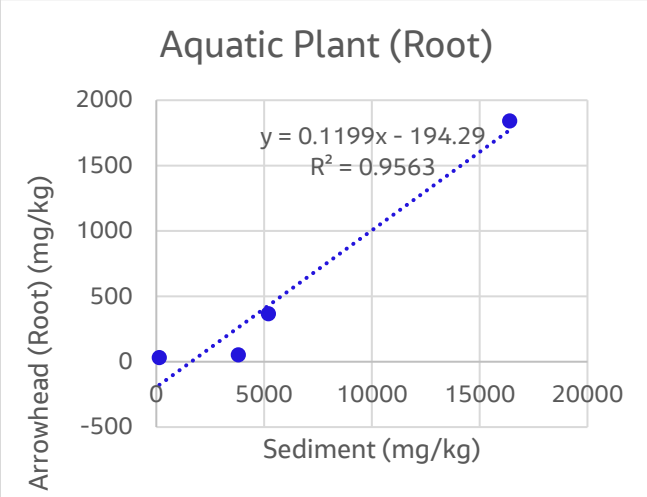
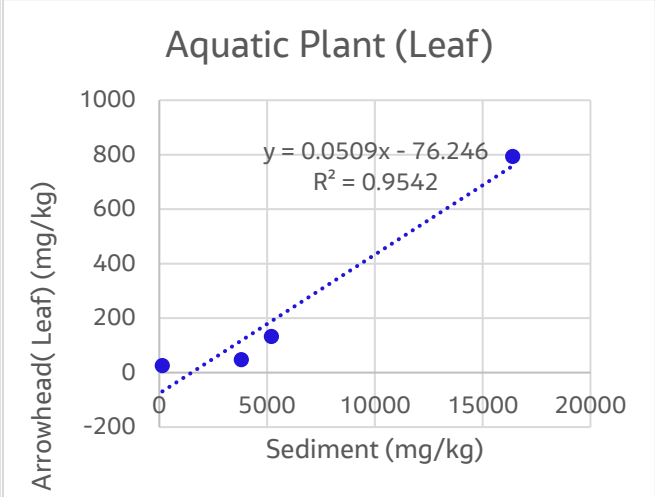
Lead





Cadmium





Zinc