
Draft Report

**Baseline Human Health
Risk Assessment for the
ASARCO LLC Hayden Plant Site
Hayden, Gila County, Arizona**

Prepared for
U.S. Environmental Protection Agency Region IX

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San Francisco, CA 94105

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CH2MHILL

2625 South Plaza Drive
Suite 300
Tempe, AZ 85282

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Acronyms and Abbreviations

$\mu\text{g}/\text{dL}$	micrograms per deciliter
$\mu\text{g lead}/\text{dL blood}$	micrograms of lead per deciliter of blood
$\mu\text{g}/\text{L}$	micrograms per liter
$\mu\text{g}/\text{m}^3$	micrograms per cubic meter
$\mu\text{g}/\text{mg}$	micrograms per milligram
95 UCL	95 percent upper confidence limit on the mean
ADD	average daily dose
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADOC	Arizona Department of Commerce
ATSDR	Agency for Toxic Substances and Disease Registry
AWC	Arizona Water Company
bgl	below ground level
Cal-EPA	California Environmental Protection Agency
CDC	Centers for Disease Control and Prevention
CLP	Contract Laboratory Program
cm^2	square centimeter(s)
COC	chemical of concern
CSF	cancer slope factor
CSM	conceptual site model
CV	comparison value
DRI	Desert Research Institute
DTSC	California Department of Toxic Substances Control
ED	exposure duration
EF	exposure frequency
ELCR	excess lifetime cancer risk
EPA	United States Environmental Protection Agency

EPC	exposure point concentration
EPCRA	Emergency Planning and Community Right-to-Know Act
ESI	Expanded Site Inspection
FPXRF	Field-Portable X-Ray Fluorescence
HEAST	Health Effects Assessment Summary Table
HHRA	Human Health Risk Assessment
HI	hazard index
HQ	hazard quotient
HWFM	Hayden Wellfield Manifold
IMPROVE	Interagency Monitoring of Protected Visual Environments
IRIS	Integrated Risk Information System
kg	kilogram(s)
kg/mg	kilograms per milligram
L/ml	liters per milliliter
LADD	lifetime average daily dose
m ³ /day	cubic meters per day
m ³ /kg	cubic meters per kilogram
MCL	maximum contaminant level
MDL	method detection limit
mg/μg	milligrams per kilogram
mg/cm ²	milligrams per square centimeter
mg/cm ² /day	milligrams per square centimeter per day
mg/cm ³	milligrams per cubic centimeter
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/kg-day	milligrams (of chemical) per kilogram (of body weight) per day
ml/hr	milliliters per hour
NAAQS	National Ambient Air Quality Standard
NAWQA	National Water Quality Assessment
NCEA	National Center for Environmental Assessment

NCP	National Contingency Plan
OEHHA	Office of Environmental Health Hazard Assessment
ORNL	Oak Ridge National Laboratory
OSWER	Office of Solid Waste and Emergency Response
PBET	Physically Based Extraction Test
pCi/L	picocuries per liter
PEF	particulate emission factor
PHA	Public Health Assessment
PM	particulate matter
PM ₁₀	particulate matter smaller than 10 microns
PPRTV	Provisional Peer Reviewed Toxicity Value
PRG	preliminary remediation goal
QA	quality assurance
QC	quality control
Qo	Older Quaternary Deposits
R&R	reverberatory furnace and roaster
RA	removal assessment
RAGS	Risk Assessment Guidance for Superfund
RCCC	Ray Consolidated Copper Company
REL	recommended exposure limit
RfC	reference concentration
RfD	reference dose
RI	remedial investigation
RME	reasonable maximum exposure
R-SRL	Arizona Residential Soil Remediation Level
SDWA	Safe Drinking Water Act
SO ₂	sulfur dioxide
SVOC	semivolatile organic compound
TAL	target analyte list
TPH	total petroleum hydrocarbons

TRI	toxic release inventory
Ts	Tertiary Sediment
TSP	total suspended particulate
UCL	upper confidence limit
USGS	United States Geological Survey
UTL	upper tolerance limit
VOC	volatile organic compound
WMFM	Winkelman Wellfield Manifold
WSC	Winkelman School Complex
XRF	X-ray fluorescence

Executive Summary

This baseline human health risk assessment (HHRA) has been prepared for the United States Environmental Protection Agency (EPA) in support of the remedial investigation (RI) to address potential exposure to contamination associated with the ASARCO LLC Hayden Plant Site (Site) in Hayden, Arizona. This HHRA presents the potential for current and future cancer risks and non-cancer health hazards to people who may be exposed to contaminants from the Site. Results from the HHRA will be one of the factors that EPA uses to determine if cleanup actions are warranted at the Site.

ES.1 Study Area

The Site is an active copper ore processing, concentrating, and smelter facility located in Gila County, Arizona. The town of Hayden is located approximately 100 miles southeast of Phoenix and 50 miles northeast of Tucson. The town of Winkelman is approximately one mile southeast of Hayden. The study area includes the towns of Hayden and Winkelman, the area encompassing the ASARCO-owned and operated ore processing operation and potentially impacted nearby areas, and the area surrounding the confluence of the Gila River and San Pedro River. The active portion of the Site consists of ASARCO's crusher, concentrator, smelter, and tailings impoundment areas.

ES.2 Risk Assessment Methodology

This HHRA was prepared in a manner consistent with EPA's Risk Assessment Guidance for Superfund, Part A (EPA, 1989), Part B (EPA, 1991b), and Part E (EPA, 2004a). The exposure assumptions provided for the general public by EPA and incorporated into this HHRA are conservative (i.e., representative of the highest exposure that is reasonably expected to occur at a site) and thus, health-protective.

This HHRA is a baseline evaluation which assumes exposure to contaminated media under current conditions without consideration of future remediation or natural attenuation of chemicals.

ES.3 Data Collection and Data Evaluation

Samples of environmental media such as soil, air, and water were collected in order to characterize the nature and extent of contamination from the Site. The data evaluation step consists of reviewing and evaluating available data. Data evaluation allows for the identification of chemicals of concern (COCs). Based on data collected historically and during the RI, COCs selected for each media include:

- Soil and dust (indoor and attic dust) – arsenic, copper, and lead.
- Air – arsenic, cadmium, chromium, copper, and lead.

- Groundwater – metals (aluminum, antimony, arsenic, cadmium, iron, manganese, molybdenum, selenium, uranium, vanadium), radionuclides, and some volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs).
- Surface water – arsenic, aluminum, iron, lead, manganese, and vanadium.
- Sediment – arsenic, copper, iron, lead, manganese, and vanadium.

Data were collected and evaluated separately for each of the various media that were evaluated in the HHRA. A detailed discussion of the data collected for the RI and used in the baseline HHRA is presented in Section 4.0, Volume I of the Remedial Investigation (RI) Report (CH2M HILL, 2008). The analytical data were reviewed according to the data evaluation procedures specified in EPA guidance documents. These procedures include evaluation of the analytical methods, quantitation limits, qualified data, blank contamination, and comparison with background concentrations.

ES.4 Exposure Assessment

Exposure assessment is the determination or estimation of the magnitude, frequency, duration, and route of exposure. Exposure assessments may consider past, present, and future exposures, using varying assessment techniques for each phase. The objective of the exposure assessment is to estimate the type and magnitude of exposures to COCs that are present at or migrating from a site.

The three primary steps in exposure assessment are identification of exposed populations, identification of exposure pathways, and quantification of exposure. A conceptual site model (CSM) is a tool used to assist with the identification of potential exposure media, human receptors, and exposure pathways. The CSM indicates complete and potentially complete exposure pathways under current and reasonably likely future conditions. An exposure pathway is defined as complete when each of the five elements of a complete pathway is present:

- A source of contaminants (e.g., smelter)
- A release mechanism (e.g., stack emissions)
 - A secondary source (e.g., off-facility soil)
 - A secondary release mechanism (e.g., soil adhering to shoes)
- An exposure medium (e.g., soil, indoor dust)
- A route of exposure (e.g., incidental ingestion, direct contact)
- A receptor (e.g., residents of Hayden and Winkelman)

ES.4.1 Exposed Populations

Residential receptors include residents of the towns of Hayden and Winkelman exposed to contaminated soil, air, groundwater, and indoor and attic dust. Adult and child residents were both evaluated; however, risk management decisions are usually made using risk/hazard results for the most sensitive receptor. For potential cancer risks, the most sensitive receptor is a resident who is exposed to contaminated media for six years as a child and 24 years as an adult. This health-protective approach is chosen to take into account the higher daily rates of soil ingestion in children, differences in body weight between adults

and children, as well as the longer duration of exposure that is anticipated for a long-term resident (EPA, 2004a). For potential non-cancer hazards, the most sensitive receptor is a child (0 to 6 years of age); therefore, although adult and child non-cancer hazards were estimated, non-cancer results for a child are discussed in this report.

Other potential receptors exposed to soil include school children in schoolyards and parks, adult golfers at the local golf course, trespassers on ASARCO properties and other locations, and recreational visitors and anglers at the nearby Gila River and San Pedro River. Site-specific exposure assumptions were developed for these receptors based on professional judgment made by EPA and CH2M HILL project personnel and an interview with a Winkelman resident about exposure-related activities of potential receptors in these areas (Hillenbrand, 2008).

ES.4.2 Exposure Pathways

Potentially complete pathways for the exposed populations may be associated with contaminated soil, air, groundwater, indoor and attic dust, and surface water and sediment from the San Pedro and Gila Rivers. Quantitative risks and hazards were evaluated for residents, trespassers, school children, and recreational visitors (including park users, golfers, swimmers, and anglers). Screening level or qualitative evaluations were completed for residential exposure to groundwater and indoor and attic dust.

Exposure pathways evaluated for soil include incidental ingestion, direct contact, and outdoor dust inhalation (resuspended particulates) by residents, trespassers, school children, park users, and golfers. The exposure pathway evaluated for air includes inhalation of ambient air by a resident using air monitoring data from the Hayden and Winkelman Stations. Exposure pathways evaluated for surface water include incidental ingestion and direct contact using a recreational swimmer scenario. Exposure pathways evaluated for sediment include incidental ingestion and direct contact using a recreational angler scenario.

ES.4.3 Estimating Contaminant Intakes

Exposure point concentrations (EPCs) for the COCs are used within the exposure assessment calculations to estimate potential chemical intake. For example, surface soil EPCs were calculated for each residential parcel or non-residential exposure area that was sampled. For soil, air, groundwater, surface water, and sediment, the EPC was either the 95 percent upper confidence limit on the mean (95 UCL) or the maximum detected concentration for chemicals with the 95 UCL exceeding the maximum concentration. For indoor and attic dust, individual sample results were compared with screening levels and associated soil results.

Quantification of exposure includes evaluation of exposure parameters that describe the exposed population (e.g., contact rate, exposure frequency and duration, and body weight). Each exposure parameter in the equation has a range of values. The reasonable maximum exposure (RME) risk estimate was used in this HHRA. An RME is the "highest exposure that is reasonably expected to occur" and is estimated using a combination of average and upper-bound values of human exposure parameters (EPA, 1989). Chemical intake is calculated by using an appropriate equation that divides exposure variables by an

averaging time. For non-carcinogenic compounds, the averaging time equals the exposure duration; whereas for carcinogenic compounds, the averaging time used is a lifetime, assumed to be 70 years (EPA, 1989).

ES.5 Toxicity Assessment

The purpose of the toxicity assessment is to weigh available evidence regarding the potential for particular contaminants to cause adverse health effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. EPA has performed the toxicity assessment step for numerous chemicals and has made available the resulting toxicity information and toxicity values which have undergone extensive peer review. The derivation of toxicity values is a complex process that includes the evaluation of many factors relating to toxicological data including the type of exposure route, duration of exposure, dose administered, physiology of the species tested, and the type of adverse health effect observed. In the toxicity assessment step, toxicity values are compiled that characterize potential adverse health effects from exposure to COCs. Uncertainty and modifying factors are commonly applied to toxicity values in order to account for uncertainties inherent in the process of relating laboratory toxicity data to relevant human exposure levels.

Cancer and non-cancer effects are evaluated differently within the toxicity assessment process. For many non-carcinogenic effects, protective mechanisms are believed to exist that must be overcome before the adverse effect is manifested. A reference dose, or RfD, is the toxicity value used most often in evaluating non-cancer effects. Because variability exists in the human population, attempts are made to identify a sub-threshold level protective of sensitive individuals in the population. For most chemicals, this level can only be estimated.

Carcinogenesis, unlike many non-carcinogenic health effects, is generally thought to be a phenomenon for which risk evaluation based on presumption of a threshold is inappropriate. For carcinogens, EPA assumes that a small number of molecular events can evoke changes in a single cell that can lead to uncontrolled cellular proliferation and eventually to a clinical state of disease. For carcinogenic effects, EPA uses a two-part evaluation in which the substance first is assigned a weight-of-evidence classification, and then a cancer slope factor is calculated.

EPA has established a hierarchy of toxicity values to be used in the risk assessment process (EPA, 2003b):

- Tier 1 – EPA’s Integrated Risk Information System (IRIS)
- Tier 2 – EPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs)
- Tier 3 – Additional EPA sources (e.g., historic Health Effects Assessment Summary Table (HEAST) and National Center for Environmental Assessment (NCEA) provisional values and non-EPA sources of toxicity information (e.g., California Environmental Protection Agency [Cal-EPA] toxicity values)

Exposure to lead in soil was evaluated using a site-specific screening level generated by the California Department of Toxic Substances Control (DTSC) Lead Risk Assessment Spreadsheet Version 7, LeadSpread Version 7 (DTSC, 2000). This model calculates a screening level that represents a concentration of lead in soil for children that is protective for a combined exposure to lead in air, drinking water, food, and soil. For the residential lead evaluation, the most conservative (health-protective) screening level available from the LeadSpread model was selected (99th percentile) based on protection of children's health.

ES.6 Risk Characterization

The risk characterization step integrates the exposure assessment and toxicity assessment into quantitative expressions of risk. To characterize potential non-carcinogenic effects, comparisons are made between estimated intakes of substances and toxicity values. Potential carcinogenic effects are evaluated by calculating probabilities that an individual will develop cancer over a lifetime exposure based on projected intakes and chemical-specific dose-response information. Potential excess lifetime cancer risk (ELCR) and non-cancer hazard index (HI) were calculated for adult and child receptors for each exposure area and medium. Human health risks are compared against the EPA risk management range of 10^{-6} to 10^{-4} for cancer risks and the HI benchmark of 1 for non-cancer hazards (EPA, 1991b). Exposure areas with ELCRs less than 10^{-6} or HI less than 1 are characterized as not posing a threat to human health for the evaluated exposed populations and pathways.

For the groundwater samples collected at Hayden and Winkelman, screening-level risks and hazards were estimated by the risk ratio method using EPA's tap water preliminary remediation goals (PRGs) (EPA, 2004b) and radionuclide PRGs from EPA's Oak Ridge National Laboratory (ORNL) website (2008b).

ES.6.1 Risks/Hazards from Background Concentrations

Details of the background data evaluation for soil are presented in a technical memorandum located in Appendix C, Volume I of the RI Report (CH2M HILL, 2008). The towns of Hayden and Winkelman are located on two different geologic settings. The soils in the Hayden area are located in the Tertiary Sediments (Ts) geological map unit, and the soils in the Winkelman area are in the older Quaternary deposit unit (Qo). Therefore, risk and hazard estimates for each geologic setting were prepared for comparison to the residential risks and hazards estimated for the residential parcels in each town and non-residential exposure areas. Ninety-five (95) percent upper tolerance limit (UTL) soil concentrations were derived from the Ts data set and were used in the background risk and hazard estimates for comparison to risks and hazards estimates from Hayden parcels; maximum concentrations of metals in Qo soil were used for the background risk and hazard estimates for the Qo data set for comparison to risks and hazards from Winkelman parcels. The background risk and HI estimates for Hayden are 3×10^{-5} and 0.9, respectively. For Winkelman, background risk and HI estimates are 2×10^{-5} and 0.6, respectively.

Air samples were not specifically collected for background purposes during the RI. However, air data from several of EPA's Interagency Monitoring of Protected Visual Environments (IMPROVE) network monitoring sites were evaluated to identify appropriate

data sets to provide background levels for an area similar to Hayden, Arizona. Data from the IMPROVE Organ Pipe National Park Station over the period from January 2006 through December 2006 were selected to best represent background conditions for comparison to the Hayden and Winkelman air monitoring data. Arsenic and cadmium were not detected in any of the 15 Organ Pipe air samples used for the background data set. Therefore, the EPCs used in the background risk calculation for those metals were based on an average of the method detection limits (MDLs). The background risk estimate for air is 6×10^{-6} .

Risk and hazards from background levels were not calculated for groundwater, surface water or sediment. Site-specific background levels were not established for groundwater since upgradient monitoring wells do not exist at the Site. Therefore, the Site groundwater concentrations were compared with arsenic levels found in groundwater from an unaffected area of Maricopa County, Arizona (USGS, 2008). For radionuclides in groundwater, national background levels (USGS, 1998) were compared with Site radionuclide levels. For surface water and sediment, three samples for each medium were collected to represent background levels. The results from the samples collected downgradient of these background locations were compared and discussed.

ES.6.2 Risk and Hazard Estimates

The following sections present the risk and hazard estimates from exposure to contaminated residential soil, nonresidential soil, air, groundwater, surface water, and sediment.

ES.6.2.1 Residential Soil

The ELCRs and HIs for soil exposure for each residential parcel evaluated are calculated based on the arsenic and copper concentrations detected in soil. Out of the 130 residential parcels evaluated, potential risks to residents due to direct contact with soil exceeded the EPA risk management range of 10^{-6} to 10^{-4} for six parcels in Hayden and one parcel in Winkelman. Eighty-three (83) of the parcels in Hayden and Winkelman have lead concentrations that exceed the site-specific screening level of 212 milligrams per kilogram (mg/kg). Risk and hazard estimates are based on the arsenic and copper concentrations detected in surface soil.

ES.6.2.2 Residential Soil – Hayden

A total of 93 parcels in Hayden have estimated ELCRs that are within the risk management range, although all are at the upper end of the risk range (between 10^{-5} to 10^{-4}). For non-cancer effects, 91 parcels show an HI that exceeds the threshold of 1, and only eight parcels have an HI that do not exceed that threshold. Seventy-two (72) of the parcels evaluated in Hayden have lead levels higher than the site-specific screening level of 212 mg/kg.

Elevated levels of lead are widespread in Hayden. No residential parcels in Hayden have lead EPCs lower than the background level of 47.9 mg/kg (for Ts). The majority of parcels (72) evaluated had EPCs higher than the site-specific lead screening level of 212 mg/kg. This site-specific screening level excludes the homegrown produce pathway. Nine of the 99 parcels evaluated do not exceed the site-specific lead screening level of 122 mg/kg, which includes the homegrown produce pathway. Comparison to the Arizona Residential Soil Remediation Level (R-SRL) of 400 mg/kg indicates that 45 of the parcels exceed this screening level.

ES.6.2.3 Residential Soil – Winkelman

In Winkelman, only one parcel (101-12-071) has an ELCR that exceeds the EPA risk management range, and has ELCR 2E-04. The other 30 parcels sampled in Winkelman have an ELCR that is within the risk management range. For non-cancer effects, 28 parcels have an HI below the non-cancer threshold of 1 and three parcels exceed this threshold. These three parcels have an HI ranging from 3 to 4. Eleven (11) parcels evaluated in Winkelman have lead concentrations that exceed the site-specific screening level of 212 mg/kg.

ES.6.2.4 Non-Residential Soil

The non-residential exposure areas include six areas in the Hayden grouping, four areas in the Winkelman grouping, 14 areas associated with the ASARCO Properties grouping, and 11 areas in the Outlying Areas grouping.

ES.6.2.5 Non-Residential Soil – Hayden

For non-residential soils in the Hayden grouping, ELCRs for five exposure areas are within and for one exposure area is below the EPA risk management range. However, the non-cancer HIs exceed 1 for Power House Wash (HI = 2) and the Hayden Community Park/Library area (HI = 4). For both of these areas, the main contributor to the HI is copper. Each of the exposure areas has a lead EPCs less than the site-specific risk-based screening level of 212 mg/kg (which excludes the homegrown produce pathway).

ES.6.2.6 Non-Residential Soil – Winkelman

The four exposure areas in the Winkelman grouping have estimated cancer risks that are within the EPA risk management range and non-cancer HIs that do not exceed the non-cancer threshold of 1. In addition, each of the four areas has a lead EPC that is less than the site-specific risk-based screening level of 212 mg/kg.

ES.6.2.7 Non-Residential Soil – ASARCO Properties

The ELCRs at all of the exposure areas in the ASARCO Properties grouping are within the EPA risk management range with the exception of the East of Hillcrest Avenue area, which exceeds 1×10^{-4} . However, the non-cancer HIs at all 14 of these exposure areas, except 5th Street Right-of-Way and Crusher Facility, exceed the non-cancer threshold of 1. HIs range from 2 (at the South of Mill Building exposure area) to 28 (at the East of Hillcrest Avenue exposure area). Each of the 14 exposure areas has a lead EPC that exceeds the site-specific risk-based screening level of 212 mg/kg for lead. These areas include the Kennecott Smelter – North End, Kennecott Smelter Basin, Kennecott Smelter Lime Plant, and Kennecott Smelter South of Lime Plant; West of Administration Building; East of Hillcrest Avenue; and North of Mill Building exposure areas.

ES.6.2.8 Non-Residential Soil – Outlying Areas

All of the exposure areas in the Outlying Areas grouping have ELCRs that are within the EPA risk management range, although one of the areas (Slag Dump) is at the upper end of the range with an estimated cancer risk of 9×10^{-5} . The non-cancer HIs do not exceed the non-cancer threshold of 1 except at the Slag Dump area where the HI is 31. Three of the 11 exposure areas have lead EPCs that exceed the site-specific risk-based screening level of

212 mg/kg for lead. These areas include the Tertiary Sediments – South of Smelter, Slag Dump, and State Route 77 exposure areas.

ES.6.3 Air

Estimated cancer risks are presented for arsenic, cadmium, and chromium detected in ambient air at the two air monitoring stations established as part of the RI. One air monitoring station is located in Hayden and the other station is located in Winkelman.

Non-cancer inhalation reference doses were not available for the air COCs evaluated. Therefore, non-cancer hazards were not considered in this ambient air assessment. The concentrations of metals in air are significantly higher in Hayden when compared to Winkelman. Both Hayden and Winkelman have levels of metals in air that are significantly higher than background levels found at the IMPROVE Organ Pipe Station.

ES.6.3.1 Air – Hayden

The ELCR from exposure to air in Hayden for arsenic, cadmium, and chromium is 1×10^{-4} which is at the upper end of the EPA risk management range. Of the total cancer risk, 80 percent of the risk contribution is from arsenic, 9 percent from cadmium, and 11 percent from chromium.

The Hayden EPC for lead of 0.183 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) is below the EPA National Ambient Air Quality Standard (NAAQS) of $1.5 \mu\text{g}/\text{m}^3$ (quarterly average). This concentration is also within the range of EPA's proposed revision to the lead NAAQS, which is 0.1 to $0.3 \mu\text{g}/\text{m}^3$ (EPA, 2008d). The Hayden EPC for copper of $1.3 \mu\text{g}/\text{m}^3$ exceeds the background air level for copper of $0.0028 \mu\text{g}/\text{m}^3$.

ES.6.3.2 Air – Winkelman

The ELCR calculated from arsenic, cadmium, and chromium data from the Winkelman air monitoring station is 4×10^{-5} , which is within the EPA risk management range. Of the total risk, 64 percent is from arsenic, 6 percent from cadmium, and 30 percent from chromium.

The Winkelman EPC for lead of $0.0281 \mu\text{g}/\text{m}^3$ is much less than the EPA NAAQS of $1.5 \mu\text{g}/\text{m}^3$ (quarterly average) and also below the range of EPA's proposed revision to the lead NAAQS, which is 0.1 to $0.3 \mu\text{g}/\text{m}^3$ (EPA, 2008d). The Winkelman EPC for copper of $0.36 \mu\text{g}/\text{m}^3$ exceeds the background air level for copper of $0.0028 \mu\text{g}/\text{m}^3$.

ES.6.4 Groundwater

Chemicals and radionuclides were evaluated for risks and hazards using a quantitative screening level approach. Each evaluation is summarized in the sections below.

ES.6.4.1 Screening-Level Chemical Evaluation

The following are the screening-level results using the risk-ratio method for the individual groundwater data groupings:

Drinking Water Aquifer: For residential exposure to drinking water from the aquifer, the ELCR is 2×10^{-4} . Arsenic contributes 100 percent of the cumulative cancer risk. The non-

cancer HI is 7 and manganese contributes more than 60 percent of the HI and is the only chemical that has a hazard quotient (HQ) that exceeds 1.

Non-Drinking Water Aquifer: For exposure to groundwater from the non-drinking water aquifer which is located beneath industrial areas, the ELCR is 4×10^{-3} . The primary risk driver is arsenic (99 percent of the cumulative cancer risk). The non-cancer HI is 35 and arsenic contributes almost 50 percent of the HI. Molybdenum contributes almost 10 percent of the HI. Arsenic, molybdenum, selenium, and vanadium have HQs that exceed 1.

Hayden Municipal Supply Well and Manifold Samples: For exposure to groundwater from the Hayden municipal supply well and manifolds, the ELCR is estimated at 9×10^{-5} , with arsenic contributing 100 percent of the total risk. The non-cancer HI is 2 with uranium contributing more than 50 percent of the HI, followed by arsenic (18 percent) and vanadium (11 percent). No individual chemical has an HQ that exceeds 1.

Winkelman Municipal Supply Well and Manifold Samples: For exposure to groundwater from Winkelman municipal supply well and manifolds, the ELCR is 1×10^{-4} with arsenic contributing over 70 percent of the total risk in addition to chlorodibromomethane (13 percent) and bromodichloromethane (10 percent). The non-cancer HI is 2 with uranium contributing over 30 percent of the total HI, followed by arsenic (26 percent) and manganese (13 percent). No individual chemical has an HQ that exceeds 1.

Tap Water: For exposure to tap water from the Hayden Library, the ELCR is 1×10^{-4} with arsenic as the only risk driver (100 percent). The non-cancer HI is 2 with uranium contributing 41 percent of the total HI in addition to arsenic (28 percent), vanadium (16 percent), and molybdenum (13 percent). No individual chemical has an HQ that exceeds 1.

For exposure to tap water from Winkelman Elementary School, the ELCR is 1×10^{-4} with arsenic as the only risk driver (100 percent). The HI does not exceed the non-cancer threshold of 1 with uranium contributing 36 percent of the cumulative HI as well as arsenic (32 percent) and vanadium (17 percent). No individual chemical has an HQ that exceeds 1.

Lead EPCs for all the data groupings were below the action level of 15 micrograms per liter ($\mu\text{g}/\text{L}$).

ES.6.4.2 Screening Level Radionuclides Evaluation

For completeness to the analytical suite, radionuclide analysis was included to evaluate groundwater quality. The following are the screening-level results using the risk-ratio method for the individual data groupings:

Drinking Water Aquifer: For residential exposure to drinking water from the aquifer, the ELCR is 5×10^{-4} . Radium 226 contributes 97 percent of the cumulative cancer risk.

Non-Drinking Water Aquifer: For residential exposure to non-drinking water from the aquifer monitoring wells, the ELCR is 4×10^{-4} . The primary risk driver is radium 226 (97 percent of the cumulative cancer risk).

Hayden Municipal Supply Well and Manifold Samples: For residential exposure to groundwater from Hayden municipal supply well and manifolds, the ELCR is 6×10^{-4} , with radium 226 contributing 98 percent of the total risk.

Winkelman Municipal Supply Well and Manifold Samples: For residential exposure to groundwater from Winkelman municipal supply well and manifolds, the ELCR is 5×10^{-6} with uranium 234 contributing 76 percent of the total risk.

Tap Water: For residential exposure to tap water from the Hayden Library, the ELCR is 4×10^{-6} with uranium 234 contributing to 65 percent of the total risk.

For residential exposure to tap water from Winkelman Elementary School, the ELCR is 4×10^{-6} with uranium 234 contributing to 74 percent of the total risk. The cumulative risk results for the Winkelman municipal supply well and manifold samples and tap water data groupings are within EPA's risk management range of 10^{-6} to 10^{-4} .

ES.6.5 Surface Water

The ELCR for exposure to surface water by the recreational swimmer is 2×10^{-6} , which is at the lower end of the EPA risk management range. The child non-cancer hazard calculated from the EPCs for aluminum, arsenic, iron, manganese, and vanadium is less than the non-cancer threshold of 1.

ES.6.6 Sediment

The ELCR for exposure to sediments by the recreational angler is 2×10^{-6} , which is at the lower end of the EPA risk management range. The exposure route which contributes the most to total risk is the oral route, which contributed 89 percent to the total risk. The child non-cancer hazard index calculated from the EPCs for arsenic, copper, iron, manganese, and vanadium is less than the non-cancer threshold of 1.

The lead concentrations in sediment are below the site-specific screening level of 212 mg/kg.

ES.6.7 Indoor and Attic Dust

A qualitative approach was selected for the indoor and attic dust evaluation because dust samples were collected from only 22 homes, which included 18 homes in Hayden and four homes in Winkelman. Dust concentrations were compared to Arizona R-SRLs. The dust samples were collected by judgmental, directed sampling where dust would tend to accumulate (along floorboards and window sills in the occupied areas, and in attics near the access doors where present) rather than by random sampling. From the 22 homes sampled, 33 investigative samples were collected, which consisted of 22 indoor dust samples (one from each home) and 11 attic dust samples.

ES.6.7.1 Hayden Indoor and Attic Dust

In Hayden, 16 of 18 indoor dust samples exceeded the arsenic Arizona R-SRL of 10 mg/kg, 14 of 18 indoor dust samples exceeded the copper Arizona R-SRL of 3,100 mg/kg, and 8 of 18 samples exceeded the lead Arizona R-SRL of 400 mg/kg. All nine attic dust samples collected in Hayden exceeded the Arizona R-SRLs for arsenic, copper, and lead.

ES.6.7.2 Winkelman Indoor and Attic Dust Results

In Winkelman, only one of the four indoor dust samples (Parcel 101-12-093 at 10.2 mg/kg) slightly exceeded the arsenic Arizona R-SRL, and no indoor dust samples exceeded the copper or lead Arizona R-SRLs. Both attic dust samples collected in Winkelman exceeded the R-SRLs for arsenic (with a maximum concentration of 54 mg/kg at Parcel 101-12-241), but neither exceeded the copper and lead Arizona R-SRLs. The indoor dust sample at Parcel 101-12-093 had antimony concentrations of 110 mg/kg, which is above the Arizona R-SRL of 31 mg/kg. In the attic dust sample at Parcel 101-12-241, the antimony concentration of 112 mg/kg was also above the Arizona R-SRL.

ES.6.8 Multi-Pathway Cumulative Risks

As a means of evaluating multi-pathway cumulative risks and comparing the relative contribution to risk from multi-pathway exposures, the sum of the residential soil and ambient air cancer risks was calculated for three soil and ambient air exposure combinations for both Hayden and Winkelman.

- Example 1 (Background). The sum of soil background risks plus air monitoring background risks. Arsenic and cadmium were not detected in any of the 15 Organ Pipe air samples used for the background data set. Therefore, the exposure point concentrations used in the background risk calculation for those metals were based on an average of the MDLs. The background risk estimate for air is 6×10^{-6} .
- Example 2 (Mid-Level Soils Concentrations). In Hayden, the sum of soil risks associated with soil arsenic at 26 mg/kg (5×10^{-5} cancer risk) plus the corresponding risks associated with air monitoring data from Hayden. For Winkelman, the sum of soil risks associated with soil arsenic at 20 mg/kg arsenic (4×10^{-5}) plus the corresponding risks associated with air monitoring data from Winkelman.
- Example 3 (High-Level Soils Concentrations). The sum of soil risks for the highest concentration property (assumed highest level of soil arsenic after soil removal action of selected properties): 132 mg/kg arsenic in Hayden, 112 mg/kg arsenic in Winkelman, plus the corresponding air monitoring risks.

ES.6.8.1 Risks from Soil plus Air – Hayden

For Hayden, the sum of residential soil plus ambient air cancer risk was 3×10^{-5} (Example 1), 2×10^{-4} (Example 2) and 4×10^{-4} (Example 3).

The soil plus air cancer risks in Hayden were greater than the background cancer risk. Ambient air cancer risks in Hayden were 1×10^{-4} ; all additional incremental risks are assumed to be due to residential soil exposure.

ES.6.8.2 Risks from Soil plus Air – Winkelman

For Winkelman, the sum of residential soil plus ambient air cancer risk was 3×10^{-5} (Example 1), 8×10^{-5} (Example 2), and 2×10^{-4} (Example 3).

The soil plus air cancer risks in Winkelman were greater than the background cancer risk. Ambient air cancer risks in Winkelman were 4×10^{-5} ; all additional incremental risks are assumed to be due to residential soil exposure.

ES.7 Uncertainty Evaluation

An uncertainty evaluation describes uncertainties associated with a risk assessment, including data gaps in toxicological and exposure assessment, and conservative assumptions or scientific judgments used to bridge these data gaps. Uncertainties, which arise at every step in the risk assessment process, are evaluated to provide an indication of the relative degree of conservatism associated with a risk estimate (EPA, 1992). The key uncertainties associated with this HHRA include the following:

- For some non-residential soil exposure areas, only one sample was collected to represent the area, which is a very limited data set. A larger sample size would allow for the calculation of a more representative exposure point concentration, and thus decrease uncertainty regarding chemical concentrations used for risk assessment at these locations.
- Site-specific exposure assumptions for the non-residential soil risk/hazard estimates are based on limited interview information and professional judgment and may not represent actual Site exposures.
- Site-specific background data sets are limited for soil and ambient air, and therefore there is uncertainty associated with the comparisons of Site data to background levels.
- A Site-specific background data set is not available for groundwater for metals, radionuclides, VOCs or SVOCs, and therefore regional and national background information was used for comparison. These regional and national background data sets may not accurately represent the range of metals and radionuclides found in the vicinity of the Site.
- The amount of a given COC (i.e., arsenic) absorbed into the body may be quite different from the amount of chemical that is actually contacted. The bioavailability factor used for ingestion of arsenic in soil was 80 percent based on limited mineralogy information. This factor may over or under estimate the actual bioavailability of the arsenic in soil at the Site.

In general, where uncertainties are associated with the steps of the HHRA process, conservative assumptions are made so that the results will be health-protective. Because of the conservative assumptions used for the risk assessment, these estimates are calculated in a way that tends to over estimate risks, and thus any actual risks are likely to be lower than these estimates.

ES.8 Summary of Results

Consistent with the CSM, the predominant exposure pathways for residents to contaminants from the Site are incidental ingestion of soil, inhalation of particulates from soil and air, and dermal contact with soil. Exposure to groundwater, indoor dust, and attic dust are considered to be minor exposure pathways and were addressed through screening-level or qualitative risk evaluations in the HHRA. Exposure to surface water and sediment are also considered to be minor exposure pathways and were evaluated using recreational exposure assumptions.

The following discussion summarizes the key findings of this HHRA:

ES.8.1 Residential Soil

Based on the baseline HHRA assumptions (i.e., assuming no remedial actions have occurred) and arsenic, copper, and lead concentrations in soil, the risk and hazard results for residential soils are as follows:

- ELCRs exceeded the EPA risk management range of 10^{-6} to 10^{-4} for six parcels in Hayden and one parcel in Winkelman. The six parcels in Hayden that exceed include 101-07-176, 101-07-089K, 101-07-089T, 101-07-034, 101-09-038, and 101-07-140 and the parcel in Winkelman that exceeds is 101-12-071.
- For non-cancer effects, the HIs exceeded the threshold of 1 for 91 parcels in Hayden and three parcels in Winkelman. The HIs that exceed the threshold range from 2 to 27.
- Lead levels exceeded site-specific lead screening level of 212 mg/kg for 72 parcels in Hayden and 11 parcels in Winkelman.

ES.8.2 Non-Residential Soil

Based on arsenic, copper, and lead concentrations in soil, the risk and hazard results for non-residential soil are as follows:

- ELCRs for five exposure areas in the Hayden grouping are within and one exposure area is below the EPA risk management range.
- ELCRs for all four non-residential soil exposure areas in the Winkelman groupings are within the EPA risk management range.
- ELCRs at all of the exposure areas in the ASARCO Properties grouping are within the EPA risk management range with the exception of the East of Hillcrest Avenue area, which exceeds 1×10^{-4} .
- All of the exposure areas in the Outlying Areas grouping have ELCRs that are within the EPA risk management range, although one of the areas (Slag Dump) is at the upper end of the range with an estimated cancer risk of 9×10^{-5} .
- For non-cancer effects, the HIs exceeded the threshold of 1 for two exposure areas in the Hayden grouping (maximum HI = 4 at Hayden Community Library), 12 exposure areas in the ASARCO Properties grouping (maximum HI = 28 at East of Hillcrest Avenue), and one exposure area in the Outlying Areas grouping (maximum HI = 31 at Slag Dump).
- Lead levels exceeded the site-specific risk-based screening level of 212 mg/kg for all 14 exposure areas in ASARCO Properties, and three exposure areas in the Outlying Areas grouping (Tertiary Sediments - South of Smelter, Slag Dump, and State Route 77).

ES.8.3 Air

The concentrations of metals in air are significantly higher in Hayden when compared to Winkelman. The ELCR from exposure to air in Hayden for arsenic, cadmium, and

chromium is 1×10^{-4} which is at the upper end of the EPA risk management range. The major contributor to risk from exposure to air is arsenic.

ES.8.4 Groundwater

Screening level ELCRs exceeded the EPA risk management range of 10^{-6} to 10^{-4} from exposure to the drinking water aquifer, non-drinking water aquifer and are at the upper end of the risk management range for Winkelman Municipal Supply Well and Manifold Samples, tap water from the Hayden Library and Winkelman Elementary School. The primary contributor to cancer risk for residential groundwater exposure is arsenic.

For non-cancer effects, the HIs exceeded the threshold of 1 for drinking water aquifer, non-drinking water aquifer, Hayden Municipal Supply Well and Manifold Samples, Winkelman Municipal Supply Well and Manifold Samples, and tap water from Hayden Library.

Screening level ELCRs from exposure to radionuclides in groundwater exceeded the EPA risk management range of 10^{-6} to 10^{-4} from exposure to the drinking water aquifer, non-drinking water aquifer, and Hayden Municipal Supply Well and Manifold Samples.

ES.8.5 Surface Water and Sediment

The ELCR for exposure to surface water by the recreational swimmer and exposure to sediments by the recreational angler are both 2×10^{-6} , which is at the lower end of the EPA risk management range. Non-cancer hazards for the child for exposure to surface water and sediment are both below the non-cancer threshold of 1.

ES.8.6 Indoor and Attic Dust

In Hayden, 16 of 18 indoor dust samples exceeded the arsenic Arizona R-SRL of 10 mg/kg, 14 of 18 indoor dust samples exceeded the copper Arizona R-SRL of 3,100 mg/kg, and 8 of 18 samples exceeded the lead Arizona R-SRL of 400 mg/kg. All nine attic dust samples collected in Hayden exceeded the Arizona R-SRLs for arsenic, copper, and lead.

In Winkelman, only one of the four indoor dust samples (Parcel 101-12-093 at 10.2 mg/kg) slightly exceeded the arsenic Arizona R-SRL. Both attic dust samples collected in Winkelman exceeded the Arizona R-SRLs for arsenic. The indoor dust sample at one parcel has an antimony concentration above the Arizona R-SRL of 31 mg/kg. In the attic dust sample one parcel has an antimony concentration above the Arizona R-SRL.

ES.8.7 Multi-Pathway Cumulative Risks

Multi-pathway cumulative risks indicate that the soil plus air cancer risks in Hayden and Winkelman were greater than the cumulative background cancer risks. The cumulative soil plus air risk associated with background conditions at 3×10^{-5} were within the EPA risk management range. The cumulative soil plus air risk for Hayden and Winkelman exceeded the EPA risk management range assuming high level metal concentrations in soil (i.e., assuming the EPCs are maximum remaining levels of soil arsenic after soil removal actions at selected properties): 132 mg/kg arsenic in Hayden, 112 mg/kg arsenic in Winkelman, plus the corresponding air monitoring risks. Assuming mid-level concentrations of arsenic in soils, the cancer risk is within the risk management range for Winkelman and exceeds the risk management range for Hayden.

ES.9 Conclusions

The HHRA results indicate that the current and former ASARCO operations have resulted in measurable impacts to soils, ambient air, and indoor dust, and to a lesser extent on groundwater, surface water and sediment. In addition, excess lifetime cancer risks exceed EPA's risk management range for some residential and nonresidential properties. Data gaps have been identified related to environmental media sampling (see Section 7.5 of Volume I the RI Report) and therefore, additional studies will be needed to fill those data gaps.

1. Introduction

This baseline human health risk assessment (HHRA) has been prepared for the United States Environmental Protection Agency (EPA) in support of the remedial investigation (RI) to address potential exposure to contamination associated with the ASARCO LLC Hayden Plant Site (Site) in Hayden, Arizona. This HHRA presents estimated current and potential future cancer risks and non-cancer hazards to receptors that may be exposed to contaminants from the Site.

This HHRA was prepared in a manner consistent with EPA's Risk Assessment Guidance for Superfund (RAGS), Part A (EPA, 1989), Part B (EPA, 1991b), and Part E (EPA, 2004a) and supporting documents and guidelines published by the California Environmental Protection Agency (Cal-EPA). The exposure assumptions for the general public provided by EPA and incorporated into this HHRA are conservative (i.e., representative of the highest exposure that is reasonably expected to occur at a site) and thus, health-protective. Results from the HHRA will be one of the factors that EPA uses to determine if cleanup actions are warranted at the Site.

The Site is an active copper ore processing, concentrating, and smelter facility located in Gila County, Arizona. The town of Hayden is located approximately 100 miles southeast of Phoenix and 50 miles northeast of Tucson. The town of Winkelman is approximately one mile southeast of Hayden (Figure 1-1). The study area includes the ASARCO Site (defined as the area encompassing the ASARCO-owned and operated ore processing operation), the towns of Hayden and Winkelman, and the area surrounding the confluence of the Gila River and San Pedro River (Figure 1-2). The active portion of the Site consists of ASARCO's crusher, concentrator, smelter, and tailings impoundment areas.

1.1 RI Process

The overall goals of the baseline HHRA are to:

- Analyze the baseline risk (the risk that could occur if no action is taken to remediate the Site), and assess the need for remedial action.
- Provide a consistent process for evaluating and documenting public health threats at EPA sites.
- Evaluate whether additional study and/or remediation is needed.
- Provide justification for performing further study or remedial action.

The overall goals of the RI at the Site are to characterize Site conditions, collect sufficient data to determine the nature and extent of contamination, and support informed risk-management decisions regarding human health and the environment.

1.2 Site Location and Description

Hayden has a population of approximately 840 residents (Arizona Department of Commerce [ADOC], 2006). ASARCO operations—including the crusher, concentrator, smelter, and tailings impoundments—surround the Hayden community on the northern, southern, and eastern edges of town. Residential areas are bounded on the western edge of town by the San Pedro Wash and are bisected by the Kennecott Wash. Public areas including a library, playground, and swimming pool are located adjacent to and west of ASARCO's concentrator facilities. Based on a 2007 reconnaissance estimate conducted as part of the RI, there are approximately 383 structures in the town of Hayden. Of this total, 301 of the structures are occupied habitable homes, 52 are uninhabitable homes, and 30 are government or commercial structures.

Winkelman has a population of approximately 435 people (ADOC, 2006). It is primarily a residential area, with a public school complex for the towns of Hayden and Winkelman on the northern edge of town, commercial development along State Route 77, and a community park along the Gila River on the eastern edge of town. Based on the 2007 reconnaissance, there are approximately 215 structures in the town of Winkelman. This includes 156 homes of which 146 homes are habitable and 10 are uninhabitable. There are also 59 government and commercial structures in Winkelman.

The active portion of the Site consists of ASARCO's crusher, concentrator, smelter, and tailings impoundment areas. The crusher is located on the north side of State Route 177 and provides crushing of ore after arriving via the Copper Basin Railway from the Ray Mine (and historically from other sources). An overland conveyor (Conveyor 9), approximately 2,000 feet long, has a portion (about 400 feet in length) that passes over some of Hayden's residential streets and directs ore from the crusher to the mill building at the concentrator facility.

A detailed description of the ASARCO operations is presented in the RI Report (Volume I). In the current Ray Complex operations, the concentrator facility starts with a milling operation that grinds the ore from Conveyor 9 to a sand size or smaller and then converts it to slurry. The ore slurry is directed to froth flotation tanks where the copper minerals are separated from the bulk of the copper ore. The copper-rich concentrate, which contains about 25 to 30 percent copper, is sent to the smelting operation for further processing (the smelter also receives concentrates directly from the Ray Mine operations). The tailings waste from the froth flotation process is sent to the thickeners, and then transported as slurry in the tailings pipeline (located next to the town of Hayden swimming pool) and deposited on Tailings Impoundments AB/BC and D.

The copper-rich concentrates are then transported to the smelter, located about 2,000 feet east-northeast of Hayden. The smelter facility includes an oxygen flash furnace, converters, anode casting, oxygen plant, and acid plant. The concentrates are unloaded and blended with fluxes, then transferred to fluid bed dryers where they are dried and stored prior to being introduced into the oxygen flash furnace. The copper concentrates ignite, melt, and partition to produce matte (approximately 55 percent copper) and slag. Slag from the smelter is transferred to open waste stockpiles located immediately southeast of the smelter operations area. During this process, sulfur from the ore is oxidized to form sulfur dioxide

(SO₂) gas, which is captured by the acid plant. The matte from the flash furnace is subsequently processed in converter furnaces to remove additional impurities and produce blister copper (approximately 98.5 percent copper). Finally, the blister copper is further processed in anode furnaces to produce copper anodes that are 99 percent pure. The anodes are shipped offsite for final processing.

The tailings impoundments are managed as part of the concentrator operations. Tailings Impoundment AB/BC is located south of State Route 177 and north of the Gila River, extends for a length of approximately 2.5 miles, and has a maximum width of one mile and a maximum height of 200 feet. The newer Tailings Impoundment D is located south of the Gila River; extends for a length of approximately two miles, has a maximum width of 1,500 feet, and a maximum height of 150 feet.

1.2.1 Site History

The Ray Mine has been mined for copper since approximately 1880. Winkelman was founded in 1887 and Hayden was founded in 1909 as a company town to provide housing for workers supporting the mining and smelting operations as described in the *Aerial Photographic Analysis of ASARCO Hayden Study Area, Gila and Pinal Counties, Arizona* (EPA, 2004c). ASARCO constructed its Hayden smelter facility in 1911 and began operations to process ore from the Ray Mine in 1912. A 300-foot stack was built in 1912 to handle reverberatory furnace and roaster (R&R) discharges, and a 250-foot stack was built in 1918 to discharge converter gases from the copper smelter. In 1933, Kennecott bought the Ray Mine from Ray Consolidated Copper Company (RCCC). The ASARCO Hayden smelter stopped receiving ore from the Ray Mine in 1958, at which time Kennecott began operation of its own Hayden smelter, which included construction of a 600-foot stack.

In 1974, the 1,000-foot double-shell concrete stack was built by ASARCO to discharge exhaust gases from the smelting operations, which replaced the 300-foot R&R stack and 250-foot converter stack. The Kennecott smelter was shut down in 1982 and selected structures were recently demolished by ASARCO. ASARCO completed modernization of its Hayden smelter in 1983, which included installation of an oxygen flash smelting furnace, construction of an oxygen plant to produce oxygen for the new furnace, construction of a second sulfuric acid plant to capture and reuse SO₂ emissions produced during smelting, and construction of a wastewater treatment plant to recover process water from the sulfuric acid plant for reuse. ASARCO's smelter renewed processing of ore from the Ray Mine in 1983, and ASARCO bought the Ray Mine Division from Kennecott in 1986. The ASARCO Ray Complex was created from control of both the mine and processing operations. In 1996, the Hayden concentrator modernization was completed (ADEQ, 2003).

An historical photographic analysis was conducted to provide support to field investigations in the area (EPA, 2004c). The analysis documents environmental conditions and industrial activities on nine different dates over a period extending from 1958 through 2004.

1.2.2 Previous Investigations

Previous investigations at the Site have been conducted by EPA and ADEQ (including primarily the Air Quality Division and the Water Quality Division). In addition, the Arizona Department of Health Services (ADHS) joined with the Agency for Toxic

Substances and Disease Registry (ATSDR) to prepare a Public Health Assessment (PHA) (ATSDR, 2002). The RI Report (Volume I) presents more extensive detail on previous investigations, whereas the following summarizes the more recent, major investigations at the Site.

1.2.2.1 Preliminary Hazard Analysis – 1999 (ATSDR, 2002)

The PHA consisted of obtaining 10 environmental soil samples within Hayden and Winkelman to evaluate levels of contamination. From June to October 1999, public health surveys were conducted on the residents of Hayden and Winkelman. Blood lead levels were evaluated for children aged 6 to 72 months, and urinary arsenic levels were checked in adults and children. The study also summarized air quality data obtained from 1991 to 1998 from the dichot particulate monitoring station maintained by ADEQ at the Hayden Jail location, and compared data against ATSDR comparison values (CVs) for arsenic (0.0002 micrograms per cubic meter [$\mu\text{g}/\text{m}^3$]), lead (National Ambient Air Quality Standard [NAAQS] of $1.5 \mu\text{g}/\text{m}^3$ - for a quarterly period), and SO_2 ($25 \mu\text{g}/\text{m}^3$ for a three-hour period). The CVs are concentrations of a chemical below which adverse health effects are unlikely to occur. The CVs are not used to define specific adverse health effects from exposure, but instead to help determine if additional contaminant-specific investigation is needed.

The PHA reported that the average concentrations of metals in soils were not above ATSDR CVs except for lead; however, the sample locations were not specified, only 10 samples were collected, and the sampling depth (0 to 6 inches below ground level [bgl]) may not have been fully indicative of surface soil impacts (0 to 2 inches bgl). Elevated urinary arsenic levels were found in a limited number of residents. The arsenic CV was exceeded in outdoor air, based on ADEQ data from the Hayden Jail, for each year from 1991 to 1998; whereas the lead CV was not exceeded based on ADEQ data from 1993 to 1997. The PHA did not include an evaluation of other metals such as chromium, cadmium, or copper. Finally, the SO_2 CV was exceeded on occasion. The PHA concluded that air quality in the Hayden and Winkelman area generally meets all federal and state air quality standards for criteria air pollutants, although some exceedances of arsenic and SO_2 CVs were reported. Brief episodes of elevated SO_2 in air may cause short-term respiratory symptoms for sensitive asthmatics a few times per month. Levels of SO_2 in air are unlikely to cause respiratory symptoms in persons without pre-existing respiratory conditions. The report noted that conclusions drawn were based on data available at the time the document was released, and that conclusions could change if data indicate that exposure has increased or decreased based on further environmental investigation (ATSDR, 2002).

1.2.2.2 Expanded Site Inspection – 2003 (ADEQ, 2003)

ADEQ, on behalf of EPA, performed an Expanded Site Inspection (ESI), which primarily included soil sampling around Conveyor 9 and other nearby areas in Hayden (groundwater and surface water/sediment sampling also were conducted). Soils from the residential areas were sampled due to the potential for the finer material on the conveyor belt that runs through town to be dispersed by wind into the residents' yards. During the ESI, ADEQ collected surface soil samples from 23 private residences located in Hayden. Elevated levels of arsenic, cadmium, copper, mercury, and lead in surface soil in both residential and public areas in Hayden were found, as well as from sampling locations in Kennecott Wash, Power House Wash, and locations near the conveyor belt. Areas assessed included the

private residences to the east of Conveyor 9 located on Smelter Road, Hillcrest Avenue, Sunnyslope Road, Ray Avenue, Velasco Avenue, and Garfield Avenue (ADEQ, 2003).

Of the 27 distinct locations sampled in Hayden, results of analyses revealed the following exceedances of the Arizona soil screening-levels (Residential Soil Remediation Levels [R-SRLs]) in surface soils:

- Arsenic levels exceeded the Arizona R-SRL of 10 milligrams per kilogram (mg/kg) at 26 locations (maximum of 67.4 mg/kg).
- Copper levels exceeded the former Arizona R-SRL of 2,800 mg/kg (the copper R-SRL was increased to 3,100 mg/kg in 2007) at 24 locations (maximum of 55,100 mg/kg).
- Lead levels exceeded the Arizona R-SRL of 400 mg/kg at three locations (maximum of 851 mg/kg).

In addition, cadmium, mercury, and zinc levels in several samples were reported as elevated, compared to the average background concentrations, but were not detected above the Arizona R-SRLs.

The ESI concluded that the elevated concentrations of metals were the result of ASARCO operations. Arsenic, cadmium, copper, and mercury in surface soil samples met the criteria of “observed contamination” (i.e., were detected in concentrations exceeding three times the average background soil concentration). Lead did not meet the criteria of “observed contamination” although 3 of 36 surface soil samples exceeded the Arizona R-SRL of 400 mg/kg. Contamination is potentially attributable to sources including dispersal of crushed ore from the conveyor belt, deposition of aerosols from smelting operations, sediment transported by surface water runoff from the concentrator operation, and deposition of tailings from wind events. Elevated concentrations at ASARCO operations were shown in sediment analysis from containment pond CP-1, which collects stormwater, wastewater, and process waters from the smelter area to contain elevated concentrations of arsenic, cadmium, chromium, copper, lead, mercury, and zinc.

1.2.2.3 Removal Assessment – 2004 (Ecology & Environment, 2004)

The EPA Emergency Response Section sampled soils in the Hayden, Kearney, and Winkelman areas to further evaluate impacts from Site operations as described in the *ASARCO Hayden Removal Assessment: Final Report* (Ecology & Environment, Inc. [E&E], 2004). The EPA Removal Assessment (RA) was focused on defining levels of metals contamination within the residential, public, and commercial areas of the three towns. Kearney did not contain elevated levels of contamination. Hence, the following summary focuses on the results of sampling in Hayden and Winkelman.

Soil samples were collected at a total of 51 locations in Hayden and 69 locations in Winkelman from randomly selected locations within an established grid. Background samples were collected at six locations along State Route 77, south of Winkelman. Surface samples were collected to a depth of approximately 2 inches bgl.

Of the 51 samples in the Hayden area, the total metals analyses revealed metals contamination above Arizona R-SRLs at 40 locations, including the following:

- Arsenic levels exceeded the Arizona R-SRL of 10 mg/kg at 40 locations (maximum of 91 mg/kg).
- Copper levels exceeded the former Arizona R-SRL of 2,800 mg/kg at 29 locations (maximum of 11,400 mg/kg).
- Lead levels exceeded the Arizona R-SRL of 400 mg/kg at one location (463 mg/kg).

In Hayden, sample locations revealing elevated copper and lead levels generally coincided with locations showing high arsenic levels, with the highest concentrations typically located near ASARCO facilities, particularly the Conveyor 9 area, east of the Conveyor 9 area near Power House Wash, and north of Hayden adjacent to the concentrator operations and the former Kennecott smelter area.

Of the 69 samples from the Winkelman area, the total metals analyses revealed the following exceedances of Arizona R-SRLs:

- Arsenic levels exceeded the Arizona R-SRL of 10 mg/kg at 16 locations (maximum of 320 mg/kg).
- Copper levels exceeded the former Arizona R-SRL of 2,800 mg/kg at seven locations (maximum of 19,000 mg/kg).
- Lead levels exceeded the Arizona R-SRL of 400 mg/kg at three locations (maximum of 485 mg/kg).

In Winkelman, elevated arsenic levels were generally located along and south of State Route 177. In addition, antimony, beryllium, and thallium also were detected at concentrations above the Arizona R-SRLs in several samples, although antimony exceeded the Arizona R-SRL at only one location. Through data validation, the beryllium and thallium concentrations were determined to likely be biased high.

An analyses of RA background samples revealed that concentrations of metals above the respective Arizona R-SRLs are not naturally occurring.

The RA concluded that surface soil contamination is present in Hayden and Winkelman. The study further concluded that the elevated concentrations of metals found throughout Hayden are likely the result of contamination dispersed from ASARCO operations. Elevated concentrations of metals in Winkelman are presumed to be the result of close proximity to ASARCO operations (exceedances in the northern portion of town), proximity to tailings disposal areas, and aerial dispersion from vehicles traveling along State Route 177, as well as rail transport facilities for copper ore.

1.2.2.4 EPA Focused Sampling Event – 2004 (Ecology & Environment, 2004)

In October 2004, in combination with the RA, soil samples were collected by EPA at five locations in Hayden and six locations in Winkelman, with the locations focused at the Hayden public pool and play area and the Winkelman school yards. A formal report of this investigation was not prepared; however, the data were subject to all necessary quality

assurance procedures. Therefore, the data are useful as a reference in understanding soil conditions.

The total metals analyses revealed the following exceedances of Arizona R-SRLs in surface soils for these 11 samples:

- Arsenic levels exceeded the Arizona R-SRL of 10 mg/kg at five locations, including four locations in Hayden and one in Winkelman (maximum concentration of 66.8 mg/kg).
- Copper levels exceeded the former Arizona R-SRL of 2,800 mg/kg at five locations in Hayden (maximum concentration of 16,900 mg/kg).
- Lead levels exceeded the Arizona R-SRL of 400 mg/kg at one location in Hayden and one in Winkelman (maximum concentration of 485 mg/kg).

Samples from Hayden containing exceedances of Arizona R-SRLs were collected at locations in the vicinity of the public pool and play structures west of and adjacent to the concentrator facility. The sample from Winkelman that contained arsenic above the Arizona R-SRL was collected at a culvert near the high school indoor swimming pool. All other samples collected at the Winkelman school area contained arsenic levels below the Arizona R-SRL.

The 2004 EPA Focused Sampling Event results reveal that surface soil contamination is present in areas where public activities are concentrated, particularly in Hayden.

1.2.2.5 Air Quality Monitoring Data (EPA, 2005)

Historically, both the ASARCO smelter and adjacent Kennecott smelter operations produced significant air emissions. At the ASARCO smelter, there were two primary stacks, including a 300-foot R&R stack (built in 1912) and a 250-foot converter stack (built in 1918). In 1920, the first air controls were installed to electrostatically remove dust from the discharge of the R&R stack. In the mid-1950s, measuring indicated that over 13,000 pounds of copper was discharged out of the two stacks on a daily basis. In 1961, production had increased and additional roaster improvements were made, and copper removal was improved to 99.7 percent efficiency, which translated to a reduction of approximately 3,000 pounds per day of copper discharged through the R&R stack. The Kennecott smelter discharged from a 600-foot stack since the time of construction in 1958, until cessation of operations in 1982. Since the early 1970s, EPA, State of Arizona, and ASARCO have collected ambient air monitoring data for SO₂ and particulate matter less than 10 microns in diameter (PM₁₀) at various locations in the Hayden area. Selected PM₁₀ samples also have been analyzed for chemical makeup of the particles.

ASARCO submits annual reports on discharges of toxic chemicals to EPA under the federal Emergency Planning and Community Right-to-Know Act (EPCRA) program, to inform communities and citizens of chemical hazards in their areas. Through EPCRA, Congress mandated that information on toxic chemical releases to the environment be collected into a database called the Toxic Release Inventory (TRI) (EPA, 2005). The ASARCO copper smelter operation in Hayden has been one of the top sources of TRI chemicals in the entire nation. ASARCO also submits annual emissions inventories of regulated air pollutants to ADEQ as a requirement of regulations adopted by the State of Arizona and EPA under the Clean Air Act. The following observations are made from a summary of TRI air emission information, as shown in Table 1-1 of the RI Report (Volume I):

1. The total air emissions were about 268 tons in 2003, 102 tons in 2004, 169 tons in 2005, and 192 tons in 2006. The decrease in 2004 is likely attributed to reduced production at the Site, which was then increased in 2005 and 2006.
2. Sulfuric acid emissions (related to SO₂ emissions) represented between 60 to 70 percent of total emissions over the four-year period.
3. For the period of 2003 through 2006, the maximum emission quantities for metals were in order for copper, zinc, lead, and arsenic (a small difference occurred in 2005 when barium emissions were greater than arsenic emissions).
4. A majority of the sulfuric acid is emitted through point sources, while the majority of metals is emitted through fugitive sources (with some exceptions, including mercury, barium, chromium, and zinc).

Particulate matter (PM) is regulated by two separate Title V Permits for the Hayden concentrator and Hayden smelter facilities. The primary PM emission points/sources at the Hayden concentrator consist of the track hopper (Wet Scrubber Stack No. 3 and No. 7), secondary crushing circuit (Wet Scrubber Stack No. 4), tertiary crushing circuit (Wet Scrubber Stack Nos. 1, 2, 5, and 6, and Fine Ore Scrubber Stacks), and miscellaneous areas (lime silo baghouse, Tailings Impoundments AB/BC and D, unpaved roads, and open areas). The primary PM emission points/sources at the Hayden smelter consist of the main stack center (flash furnace and converter primary hoods) main stack annulus (fluid bed dryers, flash furnace ventilation hoods, and converter secondary vent gas hood emissions), revert crushing system, anode furnaces, acid plant, material storage, and fugitive emissions from the flash furnaces and converters. A portion of the PM emissions at the smelter facility occur through the center and annulus of the 1,000-foot stack. ADEQ has operated a PM₁₀ sampler at the Hayden Jail monitoring station since February 1985, and has operated a total suspended particulate (TSP) monitor at the same location for preceding years. The NAAQS for PM₁₀ are 50 µg/m³ and 150 µg/m³ on an annual arithmetic mean and 24-hour average basis, respectively, with some exceedances noted.

ADEQ has collected PM samples at the Hayden Jail station using an Anderson Dichot sampler. The samples were analyzed by the X-ray fluorescence (XRF) method at Desert Research Institute (DRI) laboratory in Reno, Nevada. The Dichot sampler was equipped with two filters to measure the fine and coarse fractions of PM₁₀. The data were converted using a 24-hour sample duration and 16.7-liter per minute flow rate to calculate concentrations of metals in ambient air. Data were reviewed over the period of 1999 through 2001 (after air emission control upgrades took place at the ASARCO facility, and the last years for which ADEQ data are available) by comparing results with the EPA Region 9 ambient air preliminary remediation goals (PRG) for each metal. The comparison shows that annual average concentrations during this period exceeded the PRGs for arsenic, cadmium, and chromium. There is no ambient air PRG for copper or lead, although the quarterly NAAQS for lead of 1.5 µg/m³ was used for comparison and was not exceeded. The EPA has proposed to lower the lead NAAQS within the range of 0.10 to 0.30 µg/m³ (EPA, 2008d), and several Hayden Jail lead concentrations over this period were within this range.

1.3 Human Health Risk Assessment Process/Guidance Used

Data gathered during the RI are used in the baseline HHRA. EPA uses the results of the baseline HHRA to help determine if remedial actions are warranted, and if so, to identify and evaluate the most appropriate mitigation and/or remedial actions for the Site.

The baseline HHRA process involves the following steps:

- **Data Evaluation** – Data sets are compiled and chemicals of concern (COCs) are selected for quantitative risk and hazard calculations.
- **Exposure Assessment** – Exposure area, receptors, and exposure scenarios are identified and quantitative estimates of exposure are made.
- **Toxicity Assessment** – Toxic effects of the COCs are summarized and appropriate toxicity reference values are identified for the COCs.
- **Risk Characterization** – Quantitative estimates of cancer risks and non-cancer hazards are made.

This HHRA has been developed using the approaches and methodology based on EPA guidance including, as appropriate, the following documents:

- EPA. 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final (RAGS)*. EPA/540-1-89/002. December 15.
- EPA. 1991a. *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors"*. Interim Final. OSWER, Directive 9285.6-03. March 25.
- EPA. 1991b. *Risk Assessment Guidance for Superfund: Volume I: Human Health Evaluation Manual, (Part B: Development of Risk-based Preliminary Remediation Goals.)*. Office of Solid Waste and Emergency Response. OSWER Directive 9285.7-01B. December.
- EPA. 1997. *Health Effects Assessment Summary Tables (HEAST): Annual Update, FY 1997*. National Center for Environmental Assessment, Office of Research and Development and Office of Emergency and Remedial Response, Washington D.C. July.
- EPA. 2004a. *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final*. EPA/540/R/99/005. Office of Solid Waste and Emergency Response, Washington D.C. PB99-963312. July.
- EPA. 2004b. *User's Guide and Background Technical Document for Preliminary Remediation Goals (PRG)*. Region 9. October.
- EPA. 2008a. Integrated Risk Information System (IRIS). <http://www.epa.gov.iris/>.

This HHRA is a baseline evaluation which assumes exposure to contaminated media under current conditions without consideration of future remediation or natural attenuation of chemicals.

1.4 Document Overview

This HHRA report is organized as follows:

- Section 1 – Introduction
- Section 2 – Conceptual Site Model
- Section 3 – Data Evaluation
- Section 4 – Exposure Assessment
- Section 5 – Toxicity Assessment
- Section 6 – Risk Characterization
- Section 7 – Uncertainty Evaluation
- Section 8 – Summary
- Section 9 – References
- Figures
- Tables
- Appendices
 - A Residential Soil Risk Calculations and Summary Tables
 - B Nonresidential Soil Risk Calculations and Summary Tables
 - C Air Risk Calculations and Summary Tables
 - D Groundwater Risk Calculations and Summary Tables
 - E Surface Water Risk Calculations and Summary Tables
 - F Sediment Risk Calculations and Summary Tables
 - G Graphs Comparing Concentrations of Metals in Dust to Metals in Soil
 - H Background Risk Calculations and Graphs Comparing Background Risks to Residential Risks
 - I Notes from Interview with Winkelman Resident Regarding Exposure Assumptions
 - J Results of Mineral Speciation and Physically Based Extraction Test
 - K Handouts from EPA’s Open House and Community Meetings, January 9 and 10, 2008
 - L ATSDR ToxFAQs for Chemicals of Concern

2. Conceptual Site Model

As part of this HHRA, a conceptual site model (CSM) was prepared and provides a schematic diagram that identifies the primary source of contamination in the environment (for example, releases from a smelter stack, tailings being dispersed into town, etc.) and shows how chemicals at the original point of release move in the environment (for example, a chemical in soil might be resuspended as particulates into air). It also identifies the different types of human populations (such as residents and trespassers) that might come into contact with contaminated media (such as dust) through various exposure routes (such as incidental ingestion). Finally, the CSM identifies the potential exposure pathways (such as direct contact with soil). The CSM diagram for human exposures at the Site is presented in Figure 2-1.

2.1 Sources and Release Mechanisms

Releases from current and historic Hayden smelters and concentrator operations are the primary sources of chemical contaminants from the Site. Together, the smelters and concentrator are the major source of solid waste releases to soil, fugitive and stack emissions to air, and process wastewater releases. The primary release mechanisms are spills and releases from onsite operations, as well as fugitive and stack air emission releases. The dispersion transport media includes soil, groundwater, surface water, and air.

In addition to direct deposition from plant emissions, indoor and attic dust are accumulated from soils brought indoors by adherence to shoes and mechanical or wind-blown resuspension of soil. The potential sources of dust found in residences are many and varied. There are ASARCO-related sources, including mechanically generated emissions from the raw material handling equipment such as the hoppers, crusher, and conveyors; wind or vehicle re-entrained dusts emission from the surrounding areas (including tailings impoundments); and emissions from the smelting processes at the smelter facility (miscellaneous sources). Metals in house dust may be derived from outdoor dust and soil, as well as from ambient air. The indoor dust samples would be expected to represent shorter-term depositional activity due to recent ASARCO emissions; whereas the attic dust samples would be expected to represent longer-term, historical accumulations. This is reflected in the generally higher concentrations in the attic dust samples compared with the indoor dust samples.

2.2 Identification of Potentially Exposed Populations

Residential receptors evaluated include adult and child residents of the towns of Hayden and Winkelman. Adult and child residents were both evaluated; however, risk management decisions are usually made using risk/hazard results for the most sensitive receptor. For cancer risk, the most sensitive receptor is a resident; this receptor consists of an exposure duration of six years as a child and 24 years as an adult (referred to as a residential receptor). This health-protective approach is chosen to take into account the higher daily rates of soil ingestion in children, differences in body weight between adults

and children, and the longer duration of exposure that is anticipated for a long-term resident (EPA, 2004a). For non-cancer hazards, the most sensitive receptor is a child (0 to 6 years of age); therefore, although both adult and child non-cancer hazards were prepared, non-cancer results for a child are discussed.

Other potential receptors exposed to soil include school children in schoolyards and parks, adult golfers at the local golf course, trespassers on ASARCO properties and other locations, and recreational visitors including swimmers and anglers at the nearby Gila River and San Pedro River. Site-specific exposure assumptions were developed for these receptors based on professional judgment made by EPA and CH2M HILL project personnel and an interview with a Winkelman resident about exposure-related activities of potential receptors in these areas (Hillenbrand, 2008).

2.3 Identification of Exposure Pathways

Exposure pathways are the different ways that a receptor may contact a chemical. Each of the following components must be present for an exposure pathway to be complete (EPA, 1989):

- A potential source of a toxic substance in an environmental media, such as a smelter or concentrator
- A release mechanism, such as fugitive or stack emissions
- A contact point, such as a resident bringing soil into their homes after contaminated soil adheres to their shoes
- A route for the substance to enter the body, such as the inhalation of contaminated dust particles
- A potential receptor, such as a resident living near or on the potential source

The exposure pathways for different routes and media, considered in this HHRA are described below:

Potentially complete pathways for the exposed populations may be associated with contaminated soil, air, groundwater, indoor and attic dust, and surface water and sediment from the San Pedro and Gila Rivers. Quantitative risks were evaluated for residents, trespassers, school children, and recreational visitors (including park users, golfers, swimmers, and anglers). Screening-level and qualitative evaluations were completed for residential exposure to groundwater and indoor and attic dust.

Exposure pathways evaluated for soil include incidental ingestion, direct contact, and outdoor dust inhalation (resuspended particulates) by residents, trespassers, school children, park users, and golfers. The exposure pathway evaluated for air includes inhalation by a resident using air monitoring data from the Hayden and Winkelman stations. Exposure pathways evaluated for surface water include incidental ingestion and direct contact using a recreational swimmer scenario. Exposure pathways evaluated for sediment include incidental ingestion and direct contact using a recreational angler scenario.

Potentially incomplete pathways including potential exposure by ingestion of garden vegetables and sport fish caught in the Gila River are discussed qualitatively in Section 7, Uncertainty Analysis.

3. Data Evaluation

Samples of environmental media such as soil, air, and water were collected in order to characterize the nature and extent of contamination from the Site. The data evaluation step consists of reviewing and evaluating available data. Data evaluation allows for the identification of COCs.

This section describes the evaluation of data collected for the RI Report, Volume I (CH2M HILL, 2008). These data were used to identify contaminant distributions in surface soil, ambient air, groundwater, surface water, sediment, and indoor and attic dust. A detailed discussion of the data collected for the RI and used in the baseline HHRA is presented in Section 4.0 of the RI Report. The analytical data were reviewed according to the data evaluation procedures specified in EPA guidance documents, including *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part A* (EPA, 1989) and *Guidance for Data Usability in Risk Assessment* (EPA, 1990). These procedures include evaluation of the analytical methods, quantitation limits, qualified data, blank contamination, and comparison with background concentrations.

3.1 Soil

Surface soil sampling (0 to 2 inches bgl) was conducted at 130 residential parcels in the towns of Hayden and Winkelman, as well as 35 non-residential exposure areas. The residential parcels included 99 parcels in Hayden and 31 parcels in Winkelman. The non-residential exposure areas were categorized into four groupings – Hayden, Winkelman, ASARCO operations, and Outlying Areas. These groupings consist of six exposure areas in Hayden, four areas in Winkelman, 14 areas associated with the ASARCO operations, and 11 areas in Outlying Areas.

Although subsurface soil samples (10 to 12 inches bgl) were also collected in residential and nonresidential areas, these results were not evaluated in this risk assessment because the metals concentrations detected in the subsurface samples were generally lower than the metals detected in the surface samples, indicating that the subsurface has been less affected by the ASARCO Site. In Hayden, 96 percent of subsurface results are lower than the maximum surface results; and in Winkelman, 93 percent of subsurface results are lower than maximum surface results. In addition, the surface soil samples are considered more representative of current and more routine exposures. The soil samples were analyzed for target analyte list (TAL) metals by the EPA Contract Laboratory Program (CLP) laboratory. Although field-portable X-ray fluorescence (FPXRF) analysis also was conducted on the soil samples collected for screening purposes, only validated CLP data are used for this risk assessment.

3.1.1 Selection of Chemicals of Concern for Soil

COCs are those chemicals that are quantitatively evaluated in this HHRA. The RI analytical laboratory results for metals in soil indicate that three metals – arsenic, copper, and lead –

are the main COCs for this Site. To confirm this conclusion of the RI, the number of exceedances of the Arizona R-SRLs and/or the EPA Region 9 PRGs was determined for each metal in the residential and non-residential soils (Volume I of the RI Report, Section 4.1.2).

The Arizona R-SRLs and EPA Region 9 PRGs correspond to a cancer risk of 1×10^{-6} for carcinogenic constituents or a hazard quotient (HQ) of 1 for health hazards from non-carcinogens. The Arizona R-SRL for arsenic is based on a statewide background (naturally occurring) level and is not a risk-based concentration. The Arizona R-SRL and EPA Region 9 PRG for lead is based on the EPA Integrated Exposure Uptake Biokinetic Model for Lead in Children, which is used for predicting the range of blood lead levels in a population of young children (age 0 to 6 years) exposed to a specified set of environmental lead levels (EPA, 1994), and is based on a target-protective blood-lead level of 10 micrograms per deciliter ($\mu\text{g}/\text{dL}$).

For arsenic, nearly 100 percent of the soil samples with detected results exceeded the Arizona R-SRL (10 mg/kg) and/or PRG (0.39 mg/kg). For copper, approximately 51 percent (929 samples) of the soil samples exceeded the Arizona R-SRL and PRG of 3,100 mg/kg for copper. For lead, about 12 percent exceeded the Arizona R-SRL and PRG of 400 mg/kg for lead. Because of the large number of exceedances in residential and non-residential soil samples, arsenic, copper, and lead represent the primary COCs for the Site.

Very few exceedances of Arizona R-SRLs and PRGs were found for other metals (molybdenum, vanadium, antimony, cadmium, silver, and thallium) in soil; these metals were not selected as COCs in soil and are not considered further in this HHRA. The metals with exceedances found at the Site, in descending order by the number of exceedances, are as follows:

- Iron concentrations exceeded the PRG of 23,000 mg/kg in 122 of 281 samples (43 percent). The highest iron concentrations were found in samples collected on ASARCO Property. There were also numerous iron exceedances in residential soil samples in Hayden, and in some non-residential soil samples in the Hayden area (particularly San Pedro Wash and Power House Wash). However, there was only one iron exceedance in a residential soil sample from Winkelman.
- Molybdenum concentrations exceeded the Arizona R-SRL/PRG of 390 mg/kg in nine of 127 samples (seven percent).
- Vanadium concentrations exceeded the Arizona R-SRL/PRG of 78 mg/kg in nine of 281 samples (three percent).
- Antimony concentrations exceeded the Arizona R-SRL/PRG of 31 mg/kg in three of 281 samples (one percent).
- Cadmium concentrations exceeded the Arizona R-SRL of 39 mg/kg and the PRG of 37 mg/kg in three of 281 samples (one percent).
- Silver concentrations exceeded the Arizona R-SRL/PRG of 390 mg/kg in one of 281 samples (0.4 percent).
- Thallium concentrations exceeded the Arizona R-SRL/PRG of 5.2 mg/kg in one of 281 samples (0.4 percent).

Because of the low frequency of exceedances for molybdenum, vanadium, antimony, cadmium, silver, and thallium, and the ubiquitous nature of iron, these metals were not selected as COCs in soil. In summary, arsenic, copper, and lead represent the three primary COCs in soil at the Site and are the focus of discussion in subsequent soil sections.

Based on the preceding evaluation, arsenic is the dominant carcinogenic constituent present in residential property surface soil. Copper and lead are significant non-carcinogenic COCs in soil.

3.1.2 Background Levels for Soil

An evaluation of soil background concentrations for arsenic, copper, and lead (the primary COCs for soil) was conducted as part of the RI. The evaluation established soil background concentrations for assessment of potential environmental impacts from ASARCO operations on soils in Hayden and Winkelman.

For the geologic setting evaluation of background levels, geologic mapping indicates that the town of Hayden (including most portions of ASARCO operations) is situated in the Tertiary Sediment (Ts) geologic map unit, while the town of Winkelman is situated in the Older Quaternary Deposits (Qo) geologic map unit. Therefore, select background soil samples were identified and statistically evaluated from the Ts and Qo areas to develop background soil concentrations for Hayden and Winkelman, respectively. Figure 3-3 provides the study area map with background sample locations. The background data sets for the Ts and Qo areas were comprised of 35 Ts samples and six Qo samples.

For Hayden soils (Ts data), the 95 percent upper tolerance limit (UTL) values are:

- 12.5 mg/kg for arsenic
- 1,270 mg/kg for copper
- 47.9 mg/kg for lead

For Winkelman soils (Qo data), the maximum values were used as the default UTL, because the data set was considered non-parametric and the UTL was higher than the max. The default UTL values are:

- 9.1 mg/kg for arsenic
- 882 mg/kg for copper
- 45.8 mg/kg for lead

These UTL values for arsenic, copper, and lead were used to evaluate cancer risks and non-cancer health hazards for residential exposure to background levels of metals in soil in Hayden and Winkelman. The UTL statistic provides an accepted statistical method for determining a background soil level from a set of data (EPA, 2002).

3.1.3 Comparison Criteria for Soil

For each metal, comparison criteria were selected as a basis for evaluation of the residential and non-residential soil data. The comparison criteria are as follows:

Arsenic. For arsenic, the main comparison criteria are:

- The 10-mg/kg Arizona R-SRL

- The 12.5-mg/kg site-specific background level calculated as the UTL value for Ts soils, applicable to the Hayden area soils
- The 9.1-mg/kg site-specific maximum background level (default UTL) for arsenic in Qo soils, applicable to Winkelman area soils
- The 26-mg/kg concentration corresponds to a non-cancer hazard index (HI) of 1 using site-specific assumptions

Copper. For copper, the main comparison criteria are:

- The 3,100-mg/kg Arizona R-SRL
- The 1,270-mg/kg site-specific background level calculated as the UTL value for Ts soils, applicable to the Hayden area soils
- The 882 mg/kg site-specific maximum background level (default UTL) for copper in Qo soils, applicable to Winkelman area soils

Lead. For lead, the main comparison criteria are:

- The 400-mg/kg Arizona R-SRL
- The 47.9-mg/kg background level calculated as the UTL value for Ts soils, applicable to Hayden area soils
- The 45.8-mg/kg site-specific maximum background level (default UTL) for lead in Qo soils, applicable to Winkelman area soils
- The 212-mg/kg site-specific screening-level (assumes no homegrown produce). Appendix A contains the LeadSpread output which supports this site-specific screening-level for lead.

3.1.4 Residential Soil

Surface soil samples were collected from residential parcels in the towns of Hayden and Winkelman in January and February 2006. The surface soil samples were collected from a depth of 0 to 2 inches bgl. Nine surface soil samples were collected from each residential parcel.

Residential parcel sample locations were selected within the town limits of Hayden and Winkelman based on the potential exposure of residents to metals in soil. During the planning process for sample collection, Hayden and Winkelman were divided into 26 zones. These zones were then separated into two categories.

- Category 1: Areas in closer proximity to facility operations, which have a greater potential to be affected by aerial deposition, surface water runoff, or waste disposal activities.
- Category 2: Areas more distant from facility operations, which are likely to be affected primarily by aerial deposition.

At least 30 percent of all residential parcels assigned to Category 1 and at least 15 percent of all residential parcels assigned to Category 2 were sampled. The lower sampling frequency for the Category 2 parcels is appropriate for areas further from the contamination source. Figures 3-1 and 3-2 provide zone locations and category designations, for Hayden and Winkelman, respectively.

For the residential soil assessment, a county tax assessor parcel, which defines a residential property boundary, was used as an exposure area.

3.1.4.1 Hayden

The results of surface soil sampling conducted at the residential parcels in Hayden are presented in Figure 3-5 for arsenic, Figure 3-6 for copper, and Figure 3-7 for lead. Based on the surface soil data for each parcel, the mean, maximum, and 95 percent upper confidence limit (UCL) concentrations of arsenic, copper, and lead for each Hayden residential parcel are presented in those figures. See Section 4.1 for an explanation of how the UCL is calculated and what it represents (as an exposure point concentration [EPC]) in this HHRA. Summary statistics – including frequency of detection, minimum and maximum concentrations detected, mean, and EPCs – for the Hayden residential data are presented in Appendix A.

Arsenic. One parcel in Hayden had an arsenic UCL concentration below the Arizona R-SRL of 10 mg/kg. This parcel (101-07-185C at 9.02 mg/kg) is located in Zone 1 (Figure 3-5), the most distant zone in Hayden from the smelter and concentrator operations. Four other parcels displayed arsenic UCL concentrations slightly above the Arizona R-SRL, but below the Hayden site-specific background level of 12.5 mg/kg; these parcels (101-07-202, 101-07-234, 101-07-244, and 101-07-247) are all located in nearby Zones 2 and 3, which are the next most distant zones from active operations. The remaining 94 parcels in Hayden displayed UCL concentrations above both the Arizona R-SRL and Hayden site-specific background levels. The arsenic UCL concentrations in these 94 parcels ranged from 13.4 mg/kg in parcel 101-07-259 (Zone 4) to 540 mg/kg in parcel 101-07-089T (Zone 9, just south of the former Kennecott smelter area).

The highest arsenic concentrations observed were in Zones 7, 8, 9, 10, 16 and 17 located south of the former Kennecott smelter area and west and south of the active concentrator operations. Of the parcels sampled in these three zones, many displayed arsenic UCL concentrations greater than 26 mg/kg, the concentration for arsenic corresponding to a non-cancer HI of 1. The next most impacted areas were represented by Zones 12, 13, 14, and 15, located in the eastern part of Hayden and adjacent to the concentrator. In these zones, many parcels contained arsenic UCL concentrations above the non-cancer HI value of 26 mg/kg.

Copper. Nine of the parcels in Hayden had copper UCL concentrations below the Arizona R-SRL of 3,100 mg/kg. Eight of these nine parcels are located in Zones 1 through 4, the most distant zones in Hayden from the concentrator operations. However, all nine of these parcels had copper UCL concentrations above the Hayden background level of 1,270 mg/kg. The remaining 90 parcels in Hayden displayed UCL concentrations above the Arizona R-SRL and, therefore, well above the background level. The UCL concentrations in these 90 parcels ranged from 3,350 mg/kg in parcel 101-07-259 (Zone 4) to 39,700 mg/kg in parcel 101-09-140 (Zone 16, near the active concentrator operations).

The pattern of elevated copper concentrations is similar to that displayed for arsenic. The highest copper concentrations were in Zones 7 through 9, located south of the former Kennecott smelter area and west of the active concentrator operations; and in Zone 10 and 16, located in northeastern Hayden and immediately adjacent to ASARCO's concentrator facility.

Lead. All parcels in Hayden had lead UCL concentrations above the Hayden background level of 47.9 mg/kg. Approximately 70 parcels had lead UCL concentrations above the screening-level of 212 mg/kg, and about 45 parcels were above the Arizona R-SRL of 400 mg/kg.

The lowest lead UCL concentration was in parcel 101-07-185C (51.8 mg/kg), located in Zone 1, the most distant zone in Hayden from the concentrator operations. The highest lead UCL concentrations were in parcel 101-09-088 (92,600 mg/kg, Zone 15), parcel 101-09-004 (8,170 mg/kg, Zone 12), and parcel 101-09-077 (7,250 mg/kg, Zone 14). The lead concentration in the Zone 15 parcel was anomalously high (an order-of-magnitude above the next highest concentration) and exceeds levels in non-residential soil samples on the ASARCO Properties suggesting that other possible sources of lead may be present on this parcel. Overall, the largest number of parcels with lead UCL concentrations above the Arizona R-SRL were in Zones 10, 12, 13, 14, and 16, located in relatively close proximity to concentrator operations.

3.1.4.2 Winkelman

The results of surface soil sampling conducted at the residential parcels in Winkelman are presented in Figure 3-8 for arsenic, Figure 3-9 for copper, and Figure 3-10 for lead. The mean, maximum, and 95 percent UCL concentrations of arsenic, copper, and lead for each Winkelman residential parcel are presented in those figures. Summary statistics – including frequency of detection, minimum and maximum concentrations detected, mean, and EPCs – for the Winkelman residential data are presented in Appendix A.

Arsenic. Five parcels in Winkelman had arsenic UCL concentrations above the Arizona R-SRL (and therefore, also above the Winkelman site-specific background level). The arsenic UCL concentrations in these five parcels ranged from 16.6 mg/kg (parcel 101-12-142) to 112 mg/kg (parcel 101-12-071). These five parcels are all located in Zones 18, 19, and 21, in the central and southern portions of Winkelman.

Copper. Two parcels in Winkelman had copper UCL concentrations above the Arizona R-SRL of 3,100 mg/kg. The copper exceedances were found in two adjacent parcels in Zone 21: parcel 101-12-149 (5,130 mg/kg) and 101-12-150 (4,410 mg/kg). Arsenic UCL exceedances also were found at these two parcels. All other copper UCL concentrations in Winkelman parcels were below the Winkelman background level, with the exception of one parcel in Zone 21 (101-12-142, 1,390 mg/kg) and one parcel in Zone 20 (101-12-093, 1,040 mg/kg).

Lead. Five parcels in Winkelman had lead UCL concentrations above the Arizona R-SRL of 400 mg/kg. The highest lead exceedance was found in Zone 21, parcel 101-12-149 (2,330 mg/kg). Five additional parcels had lead UCL concentrations above the screening-level of 212 mg/kg. Of the remaining 21 Winkelman parcels, 18 displayed lead UCL concentrations above the background concentration of 45.8 mg/kg.

3.1.5 Non-Residential Soil

Surface and subsurface soil samples were collected during two sampling events (Phase I and Phase II) from non-residential areas, and were categorized into the following four main groupings:

- Hayden
- Winkelman
- ASARCO Properties
- Hayden and Winkelman Outlying Areas (Outlying Areas)

The Phase I sampling event was conducted from November 15 through November 18, 2005, and included collection of samples at 30 locations. The Phase II sampling event was conducted from February 20 through March 10, 2006, and included collection of samples at 238 locations. These locations were grouped into 35 exposure areas.

The Phase I and II non-residential soil sample locations were selected within and outside the town limits of Hayden and Winkelman based on the potential human exposure to metals by a variety of routes. Exposure to metals in soil can occur through incidental soil ingestion, soil contact with skin (dermal), and inhalation of particulates containing metals. As an example, samples were collected outside the Hayden town limits to evaluate windblown contamination from ASARCO operations. The non-residential sample locations within the four main groupings were further subdivided into exposure areas: six exposure areas in Hayden, four exposure areas in Winkelman, 14 exposure areas associated with the ASARCO Properties, and 11 exposure areas in the Outlying Areas. A list of sample locations and associated exposure areas is presented in Table 3-1.

The soil analytical results indicate that arsenic, copper, and lead concentrations in non-residential soils are affected by ASARCO operations. This is evidenced by the fact that soils at the ASARCO facilities (particularly the perimeter of the concentrator and former Kennecott smelter areas) generally contain the highest concentrations of the three metals, while non-residential soils on distant non-ASARCO Properties, including the Winkelman and upland areas, contain the lowest concentrations. The washes located near the ASARCO operations (especially Power House Wash) also appear to be directly affected by ASARCO-related activities.

Summary statistics – including frequency of detection, minimum and maximum concentrations detected, mean, standard deviation, and the 95 UCL – for the non-residential soil data in Hayden, Winkelman, ASARCO Properties, and Outlying Areas are presented in Appendix B, Tables B-1 through B-4, respectively. The following sections present the evaluation of the non-residential soil data for each main grouping.

3.1.5.1 Hayden

The exposure areas in Hayden include the following:

- Hayden Public Areas (including the Community Park and Library);
- Hayden Golf Course divided into two subareas: (1) Northwest Hayden Golf Club/Adjacent to Tailings Impoundments where higher metals concentrations were found; and (2) Remainder of Hayden Golf Club Property where lower concentrations were found;

- San Pedro Wash;
- Kennecott Avenue Wash; and
- Power House Wash.

The results of surface soil sampling conducted in Hayden Public Areas are presented in Figure 3-11 for arsenic, Figure 3-14 for copper, and Figure 3-17 for lead. Results of surface soil sampling conducted at the Hayden Golf Course are presented in Figure 3-13 for arsenic, Figure 3-16 for copper, and Figure 3-19 for lead.

Arsenic. All exposure areas associated with the Hayden grouping had at least one location that exceeded the Arizona R-SRL for arsenic of 10 mg/kg. All exposure areas except the Remainder of Hayden Golf Club Property had at least one location that exceeded the Hayden background level of 12.5 mg/kg. Four exposure areas in Hayden (Hayden Public Areas, Northwest Hayden Golf Course, San Pedro Wash, and Power House Wash) had at least one location that exceeded the risk-based concentration of 26 mg/kg, with a maximum of six exceedances in Power House Wash. The Northwest Hayden Golf Course exposure area displayed the highest concentration of arsenic for this grouping at 87.8 mg/kg in sample HGC-30-SED-0.

In addition to a sample-by-sample comparison, EPCs were compared for exposure areas. The EPC is either a 95 UCL or the maximum detected concentration, whichever is less (see Section 4.1 of this HHRA for more details). All exposure areas except the Remainder of Hayden Golf Club Property had arsenic EPCs above the background level of 12.5 mg/kg and the Arizona R-SRL of 10 mg/kg. The Hayden Public Areas and Power House Wash areas also had arsenic EPCs that exceeded 26 mg/kg.

Copper. All six exposure areas in Hayden had at least one location that exceeded both the background level and Arizona R-SRL for copper. The Hayden Public Areas displayed the highest concentration of copper in this grouping of 24,400 mg/kg in sample HPUB-01-SED-0, located near the community pool. All of the non-residential exposure areas in Hayden had copper EPCs that exceeded the background level of 1,270 mg/kg and the Arizona R-SRL of 3,100 mg/kg.

Lead. All exposure areas except the Remainder of Hayden Golf Club Property had at least one location that exceeded the background level for Hayden. Two exposure areas (Power House Wash and Northwest Hayden Golf Club) had exceedances of the site-specific risk-based screening-level of 212 mg/kg. All exposure areas in Hayden had concentrations that were less than the Arizona R-SRL for lead. The Power House Wash exposure area displayed the highest concentration of lead for this grouping at 242 mg/kg in sample PHW-SED-05AS. All exposure areas except Remainder of Hayden Golf Club Property had lead EPCs above the background level of 47.9 mg/kg, but below the site-specific risk-based screening-level of 212 mg/kg.

3.1.5.2 Winkelman

The exposure areas in the Winkelman grouping include the:

- Winkelman School Complex (WSC)
- Three Residential Properties - WSC Parcel A, WSC Parcel B, and WSC Parcel C

The three residential properties/trailers are on school property. Although people may not live year-round on these properties, residential exposure was evaluated to provide a conservative estimate of risk/hazard. The results of non-residential soil sampling conducted in Winkelman are presented in Figure 3-12 for arsenic, Figure 3-15 for copper, and Figure 3-18 for lead.

Arsenic. Sampling locations in all exposure areas in Winkelman were below the Winkelman area background level for arsenic (9.1 mg/kg) except for one sample (WSC-01-SED-0 at 14.9 mg/kg) located near the northern end of the school complex and two samples at WSC parcel A (WSCLA-05-SED-0 at 10.3 mg/kg and WSCLA-09-SED-0 at 9.7 mg/kg). Sampling locations in all exposure areas in Winkelman also were below the Arizona R-SRL for arsenic except for one sample in (WSC Parcel A (sample WSCLA-05-01-SED-0 at 14.9 mg/kg) located near the northern end of the school complex and one sample in WSC Parcel A (sample WSCLA-05-SED-0 at 10.3 mg/kg); this sample also was located near the northern end of the residential housing area. All exposure areas in Winkelman have arsenic EPCs below the Winkelman background level and the Arizona R-SRL.

Copper. Sampling locations in all exposure areas in Winkelman were below the Arizona R-SRL for copper (3,100 mg/kg). WSC Parcel A area exceeded the background level in two locations (sample WSCLA-05-SED-0 at 2,480 mg/kg and sample WSCLA-07-SED-0 at 2,670 mg/kg). At WSC Parcel B, there was an exceedance of the background level in two locations (WSCLB-06-SED-0 at 1,380 mg/kg and WSCLB-07-SED-0 at 1,270 mg/kg). WSC Parcel C also showed an exceedance of the background level in one location (sample WSC-06-SED-0 at 1,210 mg/kg). All exposure areas in Winkelman had copper EPCs below the Arizona R-SRL. Only one exposure area, WSC Parcel A, displayed a copper EPC above the Winkelman background level for copper of 882 mg/kg.

Lead. Sampling locations in all exposure areas in Winkelman were below the Arizona R-SRL for lead of 400 mg/kg and the site-specific risk-based screening-level for lead of 212 mg/kg. Only exposure area WSC Parcel A had lead concentrations above the Winkelman area background level (45.8 mg/kg) at two locations (sample WSCLA-05-SED-0 at 85.5 mg/kg and sample WSCLA-07-SED-0 at 91.4 mg/kg). Also, only exposure area WSC Parcel A, displayed a lead EPC above the Winkelman area background level for lead.

3.1.5.3 ASARCO Properties

Fourteen exposure areas are included in the ASARCO Properties grouping:

- Kennecott Smelter – North End
- Kennecott Smelter Basin
- Kennecott Smelter Plant
- Kennecott Smelter – Lime Plant
- Kennecott Smelter – South of Lime Plant
- West of Administration Building
- Thickener Tank Area
- South of Concentrator
- South of Mill Building
- East of Hillcrest Avenue
- North of Mill Building

- 5th Street Right-of-Way
- Crusher Facility
- Conveyor Drainage Tailings

The results of the non-residential soil sampling conducted at the ASARCO Properties area are presented in Figure 3-11 for arsenic, Figure 3-14 for copper, and Figure 3-17 for lead.

Arsenic. All exposure areas in the ASARCO Properties grouping except the 5th Street Right-of-Way area had at least one location that exceeded both the Arizona R-SRL of 10 mg/kg and the Hayden area background level of 12.5 mg/kg for arsenic. Nine of the 14 exposure areas (Kennecott Smelter – North End, Kennecott Smelter Basin, Kennecott Smelter Plant, Kennecott Smelter – South of Lime Plant, West of Administration Building, Thickener Tank Area, South of Concentrator, East of Hillcrest Avenue, and Conveyor Drainage Tailings) had at least one location that exceeded the risk-based concentration of 26 mg/kg. The East of Hillcrest Avenue exposure area displayed the highest concentration of arsenic (1,720 mg/kg in sample PCON-20-SED-0).

All exposure areas except the 5th Street Right-of-Way area had arsenic EPCs that exceeded the Arizona R-SRL of 10 mg/kg and the Hayden area background level of 12.5 mg/kg. Nine exposure areas (Kennecott Smelter – North End, Kennecott Smelter Basin, Kennecott Smelter Plant, Kennecott Smelter – South of Lime Plant, West of Administration Building, Thickener Tank Area, South of Concentrator, East of Hillcrest Avenue, and Conveyor Drainage Tailings) also had EPCs above 26 mg/kg.

Copper. All exposure areas had at least one location that exceeded both the background level and Arizona R-SRL for copper. The Kennecott Smelter – Lime Plant exposure area displayed the highest concentration of copper (192,000 mg/kg in sample KS-05-SED-0). All exposure areas also had copper EPCs that exceeded the background level and Arizona R-SRL.

Lead. All exposure areas except the 5th Street Right-of-Way area had at least one location that exceeded the background level for lead of 47.9 mg/kg. Nine exposure areas (Kennecott Smelter – North End, Kennecott Smelter Basin, Kennecott Smelter – Lime Plant, Kennecott Smelter – South of Lime Plant, West of Administration Building, Thickener Tank Area, South of Concentrator, East of Hillcrest Avenue, and North of Mill Building) had at least one location that exceeded the site-specific screening-level of 212 mg/kg. Three exposure areas (Kennecott Smelter – North End, Kennecott Smelter Basin, and Kennecott Smelter – South of Lime Plant) had at least one location that exceeded the Arizona R-SRL for lead. The Kennecott Smelter-North End area displayed the highest concentration of lead (552 mg/kg in sample KS-09-SED-0).

All exposure areas except the 5th Street Right-of-Way area had lead EPCs that exceeded the background level. Seven exposure areas (Kennecott Smelter – North End, Kennecott Smelter Basin, Kennecott Smelter – Lime Plant, Kennecott Smelter – South of Lime Plant, West of Administration Building, East of Hillcrest Avenue, and North of Mill Building) had EPCs above the site-specific lead screening-level of 212 mg/kg. Three exposure areas (Kennecott Smelter – North End, Kennecott Smelter Basin, and Kennecott Smelter – South of Lime Plant) had EPCs above the Arizona R-SRL for lead.

3.1.5.4 Outlying Areas

The Outlying Areas grouping includes 11 exposure areas:

- Tertiary Sediments – South of Smelter
- Slag Dump
- State Route 77
- Tailings Impoundment AB/BC
- Tailings Impoundment D
- Older Quaternary Deposits – North of Hayden
- Cretaceous/Tertiary Intrusives and Volcanics
- Tertiary Sediments – South of Winkelman
- Quaternary Alluvium
- Older Quaternary Deposits – North of Tailings Impoundment D
- Tertiary Sediments – West of Concentrator

The results of the non-residential soil sampling conducted at the Outlying Area grouping are presented in Figure 3-13 for arsenic, Figure 3-16 for copper, and Figure 3-19 for lead.

Of the 11 exposure areas in the Outlying Areas, six areas consist of only one sample. The samples in these exposure areas were grouped based on soil type. They include:

- Tertiary Sediments – South of Smelter
- Older Quaternary Deposits – North of Hayden
- Cretaceous/Tertiary Intrusives and Volcanics
- Tertiary Sediments – South of Winkelman
- Older Quaternary Deposits – North of Tailings Impoundment D
- Tertiary Sediments – West of Concentrator

Due to the small sample size, there is uncertainty with the risk/hazard estimates associated with these exposure areas.

Arsenic. Seven exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, Older Quaternary Deposits – North of Hayden, and Tertiary Sediments – West of Concentrator) in the Outlying Areas grouping had at least one location that exceeded the Arizona R-SRL for arsenic of 10 mg/kg. Six exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, and Tertiary Sediments – West of Concentrator) had at least one location that exceeded the Hayden background level of 12.5 mg/kg. Five exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, and Tertiary Sediments – West of Concentrator) had at least one location that exceeded the risk-based concentration of 26 mg/kg. The Slag Dump area displayed the highest concentration of arsenic (361 mg/kg in sample SDD-01-SED-0).

Seven exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, Older Quaternary Deposits – North of Hayden, and Tertiary Sediments – West of Concentrator) had arsenic EPCs above the Arizona R-SRL of 10 mg/kg. Six exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, and

Tertiary Sediments – West of Concentrator) had EPCs above the background level of 12.5 mg/kg. Four exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, and Tertiary Sediments – West of Concentrator) had arsenic EPCs that exceeded 26 mg/kg.

Copper. Seven exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, Older Quaternary Deposits – North of Hayden, and Tertiary Sediments – West of Concentrator) had at least one location that exceeded the site-specific background level for copper. Six exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, and Tertiary Sediments – West of Concentrator) had at least one location that exceeded the Arizona R-SRL. The Slag Dump exposure area displayed the highest concentration of copper (380,000 mg/kg in sample PSMT-01-SED-0).

Seven exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, Older Quaternary Deposits – North of Hayden, and Tertiary Sediments – West of Concentrator) had EPCs that exceeded background levels for copper. Five areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment D, and Tertiary Sediments – West of Concentrator) had copper EPCs that exceeded the Arizona R-SRL.

Lead. Six exposure areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, and Tertiary Sediments – West of Concentrator) had at least one location that exceeded the background level for lead. Three areas (Tertiary Sediments – South of Smelter, Slag Dump, and State Route 77) had at least one location that exceeded the site-specific screening-level of 212 mg/kg. Only the Slag Dump area had many samples that exceeded the Arizona R-SRL; this area also displayed the highest concentration of lead (1,230 mg/kg in sample PSMT-01-SED-0).

Six areas (Tertiary Sediments – South of Smelter, Slag Dump, State Route 77, Tailings Impoundment AB/BC, Tailings Impoundment D, and Tertiary Sediments – West of Concentrator) had EPCs that exceeded background levels of lead. Three areas (Tertiary Sediments – South of Smelter, Slag Dump, and State Route 77) had EPCs that exceeded the site-specific screening-level of 212 mg/kg. Only the Slag Dump area had an EPC above the Arizona R-SRL.

3.2 Air Monitoring

The ambient air data set was compiled using approximately one year of data collected from two RI air monitoring stations during the ongoing air sampling program in the towns of Hayden and Winkelman. Air samples were not specifically collected for background purposes during the RI. However, air data from several of EPA's Interagency Monitoring of Protected Visual Environments (IMPROVE) network monitoring sites were reviewed to identify appropriate data sets to provide background levels for an area similar to Hayden, Arizona. Air data collected between January 2 and December 4, 2006, from the IMPROVE Organ Pipe National Park Air Monitoring Station located in the Sonoran Desert (which is similar to the Site setting), were selected to best represent Arizona background conditions for comparison to the Hayden and Winkelman air monitoring data collected during the RI.

Risks from exposure to air not impacted by the Site were estimated using the background air data set.

3.2.1 Selection of Chemicals of Concern for Air

The COCs selected for evaluation in ambient air at Hayden and Winkelman include arsenic, cadmium, chromium, copper, and lead. Arsenic, copper, and lead are the primary soil COCs, so these metals are of interest in ambient air. Cadmium and chromium exceedances of ambient air screening-levels were observed in the data from the air monitoring program, so those metals are also included as air COCs.

The manganese concentration in one Winkelman sample exceeded the ambient air PRG screening-level of $0.051 \mu\text{g}/\text{m}^3$. Based on this low frequency of exceedance, manganese is not considered a COC in air for this evaluation.

3.2.2 Background Air Monitoring Data

A general assessment of background air concentrations was conducted; however, a background air monitoring station was not installed as part of the RI. Air monitoring data collected from remote locations with minimal anthropogenic contributions can be used to estimate background levels of metals in ambient air. The available background air quality data were used for comparison with RI data from the Hayden and Winkelman RI air monitoring stations. Data from several remote monitoring locations in Arizona were reviewed to identify appropriate data sets to provide background levels for an area similar to Hayden, Arizona. The monitoring data for the monitoring station located at the IMPROVE Organ Pipe National Park were selected based on the location of the station in the Sonoran Desert, which is similar to the Site setting. Ambient air concentration data from the IMPROVE Organ Pipe Station was selected for use as background air concentrations of metal contaminants for this HHRA.

Using selected Organ Pipe National Park data, the 95 percent UCL concentrations for the five air-related COCs are:

- Arsenic - $0.0004 \mu\text{g}/\text{m}^3$
- Cadmium - $0.0006 \mu\text{g}/\text{m}^3$
- Chromium - $0.00072 \mu\text{g}/\text{m}^3$
- Copper - $0.0028 \mu\text{g}/\text{m}^3$
- Lead - $0.00164 \mu\text{g}/\text{m}^3$

Arsenic and cadmium were not detected in any of the 15 Organ Pipe air samples used for the background data set. Therefore, the 95 percent UCLs for those metals were based on an average of the method detection limits (MDLs). The background air metals data from the Organ Pipe station allowed for a direct comparison with metals data collected from the Hayden and Winkelman RI air monitoring stations.

3.2.3 Hayden and Winkelman Air Monitoring Data

The purpose of the air monitoring task was to characterize the concentrations of contaminants from the Site in ambient air at discrete locations in Hayden and Winkelman. This was conducted by installing PM_{10} and meteorological stations in Hayden and

Winkelman. The locations of the two RI ambient air monitoring stations are shown in Figure 3-4.

The air monitoring data set collected and compiled from the Hayden station consists of data from samples collected from October 22, 2006 through November 7, 2007. The Hayden air data set includes 57 samples. From the Winkelman station, the air samples were collected from November 21, 2006 through November 1, 2007, and include 55 air samples.

For the Hayden data, the 95 percent UCL used in the risk evaluation or EPC comparison as an EPC is:

- 4.6E-02 $\mu\text{g}/\text{m}^3$ arsenic
- 2.5E-03 $\mu\text{g}/\text{m}^3$ chromium
- 1.6E-02 $\mu\text{g}/\text{m}^3$ cadmium
- 1.3E+00 $\mu\text{g}/\text{m}^3$ copper
- 1.8E-01 $\mu\text{g}/\text{m}^3$ lead

For the Winkelman data, the 95 percent UCL used in the risk evaluation or EPC comparison as an EPC is:

- 1.0E-02 $\mu\text{g}/\text{m}^3$ arsenic
- 1.7E-03 $\mu\text{g}/\text{m}^3$ chromium
- 2.3E-03 $\mu\text{g}/\text{m}^3$ cadmium
- 3.6E-01 $\mu\text{g}/\text{m}^3$ copper
- 2.8E-02 $\mu\text{g}/\text{m}^3$ lead

Summary statistics for the air data collected from the two monitoring stations, including the 95 percent UCLs, are presented in Appendix B.

Air quality data were compared to the EPA Region IX PRGs for ambient air and the NAAQS for lead.

3.3 Groundwater

Groundwater was identified as a medium for evaluation of potential risks and hazards in this HHRA to assess whether contamination from the Site would affect potential receptors. Hayden's drinking water is supplied by a wellfield, which is operated by ASARCO and is located south of Hayden and east of Tailings Impoundment AB/BC. Winkelman's drinking water is supplied by three wells, which are operated by the Arizona Water Company, located east of town within the community park adjacent to the Gila River as described in the *Expanded Site Inspection Report: ASARCO, Inc., Hayden Plant.* (ADEQ, 2003).

Groundwater sampling was conducted from monitoring well, production well and manifold, and drinking water tap locations. Sampling was performed in February/March 2006 (winter event) and August/September 2006 (summer event).

A total of 22 monitoring wells were selected for sampling during each event and included the ASARCO-owned H-series wells (H-1 through H-11), ARU-1, ARU-8, MW-2, MW-4, S-4A, SM-2, LC-1, and newly installed, EPA-owned wells GW-01(R), GW-02, GW-03, and GW-06. In general, the groundwater data set evaluated in this HHRA is limited. Only

two sampling events were conducted, and due to the deviations discussed in Volume I of the RI report (CH2M HILL, 2008), wells H-7, SM-2, GW-01, and GW-02 were not sampled during the winter sampling event. Furthermore, not all monitoring wells were sampled for all the analyte suites. However, when a monitoring well was sampled during both sampling events, the samples were analyzed for the same suites during each event. The Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs) were exceeded for a few chemicals in the groundwater data set. Currently, no known residents have private wells. Residents receive their drinking water from either the Hayden or Winkelman wellfields.

The Hayden wellfield is operated by ASARCO, and consists of 19 supply wells installed in the shallow alluvial aquifer, although not all wells are operated at all times. ASARCO cycles the Hayden wells on and off to meet the water demands of the mining operations. Three of these supply wells were selected for sampling; the wellfield manifold was also sampled. The selection of the supply wells for sampling in the Hayden wellfield was by location. One well was chosen to represent the north end, one for the central portion, and one to represent the south end of the wellfield.

The Winkelman wellfield is operated by Arizona Water Company (AWC), and consists of two supply wells installed in a deeper portion of the alluvial aquifer. Both wells and the wellfield manifold were sampled. Samples from the manifold represent water that comes out of the two supply wells after blending, but is not tap water, in that it has not traveled through the piping/distribution system to the end users. The production wells and manifolds sampled included Hayden wellfield wells HWF-15, HWF-21, and HWF-26, the Hayden wellfield manifold (HWFM), Winkelman wells 3 and 4 (WM-3 and WM-4), and the Winkelman wellfield manifold (WMFM).

Each production well was sampled for the same analytical suites during each event. The following analytical suites were analyzed for:

- Inorganics: total and dissolved metals
- Volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and total petroleum hydrocarbons (TPH)
- Radiochemistry
- General geochemistry

The tap water samples included the samples from the drinking fountain at the Hayden Library and at the Winkelman Elementary School. These samples were analyzed for total and dissolved metals, general water quality parameters, and radionuclides. Only total metal results were used in this risk assessment; dissolved metal results were not used because it is assumed that residents may not have a filter on their water supply system.

3.3.1 Background Levels for Groundwater

A background groundwater quality study was not in the scope of work for the RI. A detailed background study would be needed to further assess background concentrations. However, for data evaluation purposes, regional/national background data sets were used for comparisons.

3.3.2 Groundwater Data Groupings

For the purposes of this HHRA, the data collected from the various wells, manifolds, and tap water locations were divided into data groupings as follows (Table 3-2 and Figure 3-20):

- **Drinking water aquifer:** Data from monitoring wells H-1, H-2A, H-3, H-4, H-5, H-6, H-10, H-11, ARU-1, ARU-8, GW-03, and S-4A.
- **Non-drinking water aquifer:** Data from monitoring wells H-7, H-8, H-9, LC-1, MW-2, MW-4, GM-01R, GW-06, MW-2, MW-4, SM-2, and GW-02. The wells in the non-drinking water aquifer monitoring well grouping are closer to the facility so they may show higher risks/hazards; however, there are no current exposure pathways for the groundwater in this grouping.
- **Hayden municipal supply wells and manifolds:** Data from Hayden wells HWF-15, HWF-21, and HWF-26, and the Hayden manifold HWFM.
- **Winkelman municipal supply wells and manifolds:** Data from Winkelman wells WM-3 and WM-4, and the Winkelman manifold WWFM.
- **Tap water from Hayden Library and Winkelman Elementary School** (samples obtained from drinking fountains in Hayden Library [HL] and Winkelman [WSCH]).

Groundwater quality data were compared to the EPA MCLs and EPA Region IX PRGs for tap water.

3.3.3 Selection of Chemicals of Concern for Groundwater

For the purpose of the screening-level assessment, all detections in the groundwater sample results are considered as COCs for evaluation. For each group, chemicals detected in groundwater, are as follows:

- **Drinking water aquifer:** Aluminum, antimony, arsenic, cadmium, iron, manganese, molybdenum, selenium, uranium, vanadium and radionuclides – radium 226, total uranium, uranium 234, uranium 235, and uranium 238 activity.
- **Non-drinking water aquifer:** Aluminum, antimony, arsenic, cadmium, iron, manganese, molybdenum, selenium, uranium, vanadium, bis(2-ethylhexyl)phthalate, naphthalene, bromodichloromethane, chloroform, tetrachloroethene, trichloroethene, and radionuclides – radium 226, total uranium, uranium 234, uranium 235, and uranium 236 activity.
- **Hayden municipal supply wells and manifolds:** Arsenic, manganese, molybdenum, selenium, uranium, vanadium, and radionuclides – radium 226, total uranium, uranium 234, uranium 235, uranium 238 activity.
- **Winkelman municipal supply wells and manifolds:** Arsenic, iron, manganese, molybdenum, selenium, uranium, vanadium, bis(2-ethylhexyl)phthalate, 1,2-dibromoethane, bromodichloromethane, chlorodibromomethane, and radionuclides – total uranium, uranium 234, uranium 235, and uranium 238 activity.

- **Tap water from Hayden Library:** Aluminum, arsenic, manganese, molybdenum, selenium, uranium, vanadium and radionuclides – total uranium, uranium 234, uranium 235, and uranium 238 activity.
- **Tap water from Winkelman Elementary School:** Arsenic, manganese, molybdenum, selenium, uranium, vanadium and radionuclides – total uranium, uranium 234, uranium 235, and uranium 238 activity.

3.4 Surface Water

Surface water samples were collected during two events from locations along the Gila River and San Pedro River. The two sampling events occurred in the winter (March 7 and 8, 2006) and the summer (August 22 and 23, 2006). Surface water samples were collected at 11 locations along the Gila River and two locations along the San Pedro River. These sampling locations are categorized into two groups:

- Background surface water samples
- In-stream surface water in the vicinity of and downstream of ASARCO operations

The sample locations were selected based on:

- The potential source areas
- Interpretation of distribution of contamination
- Geographic constraints
- Property ownership constraints
- Personnel access constraints

Surface water samples collected at these locations address the need to characterize the potential exposures of recreational users to this medium. Three sampling locations (GR-SW-01, GR-SW-02, and SPR-SW-01) located upstream of ASARCO operations are not considered to be affected by ASARCO operations, and therefore, are considered background surface water locations for the purposes of this investigation (see Section 3.4.1 for background discussion). Six sample locations (GR-SW-03 through GR-SW-07 and SPR-SW-02) are located in the vicinity of ASARCO facilities; and four sampling locations (GR-SW-08 through GR-SW-11) are located further downstream of ASARCO operations, beyond the tailings impoundments.

These samples were analyzed for metals and general water quality parameters. Figures 3-21 and 3-22 show the surface water sampling locations and concentrations for selected metals. Only total metal results were used in this risk assessment, because potential exposure of recreational users would be to unfiltered surface water. For each metal, the concentrations were compared with EPA tap water PRGs for selection of COCs (see Section 3.4.3). Summary statistics – including frequency of detection, minimum and maximum concentrations detected, mean, standard deviation, and 95 UCL – for the surface water data in the Gila and San Pedro Rivers are presented in Appendix E. Section 4.1 provides an explanation of how the 95 UCL is calculated and what it represents (as an EPC) in this HHRA.

3.4.1 Background Levels for Surface Water

In the Gila River samples, all metal concentrations except arsenic are below the EPA tap water PRGs. Total and dissolved arsenic concentrations exceed the PRG of 0.045 micrograms per liter ($\mu\text{g}/\text{L}$), with concentrations ranging from 2.5 $\mu\text{g}/\text{L}$ to 7 $\mu\text{g}/\text{L}$. Total background copper concentrations range from 4.9 $\mu\text{g}/\text{L}$ to 15.4 $\mu\text{g}/\text{L}$, and total lead concentrations range from 0.68 $\mu\text{g}/\text{L}$ to 4.6 $\mu\text{g}/\text{L}$, with concentrations several times higher in the summer sampling event relative to the winter sampling event.

In the San Pedro River samples, all metal concentrations except arsenic are below the EPA tap water PRGs. The total and dissolved arsenic concentrations exceed the PRG of 0.045 $\mu\text{g}/\text{L}$, with concentrations ranging from 5.2 $\mu\text{g}/\text{L}$ to 8.5 $\mu\text{g}/\text{L}$. Maximum total copper and total lead concentrations were 34.0 $\mu\text{g}/\text{L}$ and 24.3 $\mu\text{g}/\text{L}$, respectively. For both rivers, concentrations for most metals were higher in the summer sampling event relative to the winter sampling event.

3.4.2 Surface Water in the Vicinity and Downstream of ASARCO Site

The surface water sampling results at locations close to and downstream of ASARCO operations indicate the following:

- Elevated concentrations of several analytes were clearly evident at the two Gila River sampling locations (GR-SW-06 and GR-SW-07) located between the tailings impoundments, compared to other upstream and downstream locations. The total and dissolved concentrations of aluminum, arsenic, barium, beryllium, calcium, cadmium, chromium, cobalt, copper, iron, lead, magnesium, manganese, nickel, potassium, sodium, thallium, vanadium, and zinc, as well as total mercury, molybdenum, selenium, and silver, were generally higher in these two samples than in other Gila River samples. These elevated concentrations were most pronounced in samples collected in the summer sampling event. Although no winter event samples exceeded PRGs (with the exception of arsenic), several exceedances were noted in the summer event samples at GR-SW-06 and/or GR-SW-07 only, and these levels also were considerably above background levels measured in GR-SW-01 and GR-SW-02:
 - Aluminum (62,000 $\mu\text{g}/\text{L}$ in GR-SW-06 and 52,800 $\mu\text{g}/\text{L}$ in GR-SW-07 [duplicate]) exceeded the PRG of 36,000 $\mu\text{g}/\text{L}$.
 - Arsenic (16.8 $\mu\text{g}/\text{L}$ in GR-SW-06 and 13.9 $\mu\text{g}/\text{L}$ in GR-SW-07 [duplicate]) exceeded the PRG of 0.045 $\mu\text{g}/\text{L}$.
 - Iron (34,500 $\mu\text{g}/\text{L}$ in GR-SW-06 and 31,500 $\mu\text{g}/\text{L}$ in GR-SW-07 [duplicate]) exceeded the PRG of 11,000 $\mu\text{g}/\text{L}$.
 - Manganese (3,450 $\mu\text{g}/\text{L}$ in GR-SW-06 and 2,510 $\mu\text{g}/\text{L}$ in GR-SW-07) exceeded the PRG of 880 $\mu\text{g}/\text{L}$.
 - Vanadium (56.6 $\mu\text{g}/\text{L}$ in GR-SW-06 and 49.2 $\mu\text{g}/\text{L}$ in GR-SW-07) exceeded the PRG of 36 $\mu\text{g}/\text{L}$.
- Surface water samples from the San Pedro River location (SPR-SW-02) displayed higher concentrations for some analytes as compared to the Gila River sampling locations.

However, only arsenic showed exceedances of the PRG in the San Pedro River. Despite the increased concentrations observed in the San Pedro River samples and in the Gila River samples GR-SW-06 and GR-SW-07, the downgradient samples did not show PRG exceedances (with the exception of arsenic).

Surface water sample results are compared with MCLs and EPA Region 9 tap water PRGs, which are protective of human health.

3.4.3 Selection of Chemicals of Concern for Surface Water

For purposes of this baseline HHRA, the surface water sample results are compared with EPA tap water PRGs, which are based on human health risks. The metals with exceedances found at the Site are as follows:

- Arsenic: 22 samples, including two duplicates, exceeded the PRG of 0.045 µg/L.
- Aluminum: three samples, including one duplicate, exceeded the PRG of 36,000 µg/L.
- Iron: three samples, including one duplicate, exceeded the PRG of 11,000 µg/L.
- Manganese: three samples, including one duplicate, exceeded the PRG of 880 µg/L.
- Vanadium: three samples, including one duplicate, exceeded the PRG of 36 µg/L.

The maximum copper concentration of 172 µg/L is well below the EPA tap water PRG of 1,500 µg/L; therefore, it was not considered a COC in surface water. There is no tap water PRG for lead; however, since lead was detected above the federal action level of 15 µg/L, it is considered a COC in surface water.

3.5 Sediments

In-stream sediment samples were collected during two events from locations along the Gila River and San Pedro River. These samples were collected concurrently with the surface water samples during two sampling events. Sediment samples were collected at 11 locations along the Gila River and two locations along the San Pedro River. These sampling locations are categorized into two groups:

- Background sediment samples
- In-stream sediment in the vicinity of and downstream of ASARCO operations

The sample locations were selected based on:

- The potential source areas
- Interpretation of distribution of contamination
- Geographic constraints, property ownership constraints
- Personnel access constraints

Sediment samples collected at these locations address the need to characterize the potential exposures of recreational users to this medium.

Three sampling locations (GR-SED-01, GR-SED-02, and SPR-SED-01) located upstream of ASARCO operations are not considered to be affected by ASARCO operations, and

therefore, are considered background sediment locations for the purposes of this investigation. Six in-stream sediment sample locations (GR-SED-03 through GR-SED-07, and SPR-SED-02) are located in the vicinity of ASARCO facilities and four sampling locations (GR-SED-08 through GR-SED-11) are located further downstream of ASARCO operations, beyond the tailings impoundments.

All sediment samples collected were analyzed for metals. Figure 3-23 depicts the in-stream sediment sampling locations, and also presents concentrations for selected metals. For each metal, the concentrations were compared with Arizona R-SRLs and/or PRGs. Summary statistics—including frequency of detection, minimum and maximum concentrations detected, mean, standard deviation, and the 95 UCL—for the sediment data in the Gila and San Pedro Rivers are presented in Appendix F. Section 4.2 provides an explanation of how the 95 UCL is calculated and what it represents (as an EPC) in this HHRA.

3.5.1 Background Levels for Sediment

For two in-stream sediment sample locations (GR-SED-01 and GR-SED-02), the maximum concentrations of arsenic (4.4 mg/kg), iron (28,800 mg/kg), manganese (2,270 mg/kg), and vanadium (91.2 mg/kg) exceeded the Arizona R-SRL and/or PRG, whereas only arsenic (maximum 2.6 mg/kg) exceeded these criteria at the upstream San Pedro River location (SPR-SED-01). For upstream Gila River in-stream sediment samples GR-SED-01 and GR-SED-02, the maximum concentrations of other metals of concern, including copper (191 mg/kg), lead (11.7 mg/kg), and chromium (14 mg/kg), were well below the Arizona R-SRL and/or PRGs; and slightly lower concentrations of these metals were observed in the upstream San Pedro River sediment sample (SPR-SED-01).

The presence of elevated concentrations of some metals in upstream sediment samples are likely the result of contributions from other side drainages into the Gila River.

3.5.2 In-stream Sediment in the Vicinity and Downstream of ASARCO Operations

The sampling results for in-stream sediment samples in the vicinity of and downstream of ASARCO operations indicate the following (results presented below are the highest from among the winter and summer sampling events):

- Arsenic concentrations range from 1.1 mg/kg to 5 mg/kg, consistent with levels found in the upstream samples, and are similar to the samples collected adjacent to ASARCO operations.
- Iron concentrations are above the PRG in GR-SED-07 (24,700 mg/kg), GR-SED-08 (26,300 mg/kg), and GR-SED-11 (23,800 mg/kg), but these levels are consistent with those found in upstream samples.
- Manganese concentrations are above the PRG in GR-SED-03 (2,410 mg/kg), but this level is consistent with upstream samples.
- Vanadium concentrations are lower than the maximum concentration in the upstream sediment samples.

- Copper concentrations show small relative increases in samples collected near and downgradient of the tailings impoundments (GR-SED-07 and GR-SED-08), but concentrations are generally consistent with those found in upstream samples.
- Lead and chromium concentrations show small relative increases in samples collected adjacent to and downgradient of ASARCO operations (GR-SED-06 through GR-SED-11), but concentrations are not significantly above those found in upstream samples.

Sediment sample results are compared with Arizona R-SRLs and EPA Region 9 Residential Soil PRGs, which are protective of human health.

3.5.3 Selection of Chemicals of Concern for Sediments

The following metals were found at levels above the Arizona R-SRLs and PRGs in in-stream sediment samples:

- Arsenic
- Iron
- Manganese
- Vanadium

In addition, copper and lead, which are primary COCs for soil (defined in Section 3.1.1), were evaluated as COCs for sediments.

3.6 Indoor and Attic Dust

This section describes indoor and attic dust sampling activities conducted at 22 homes in Hayden and Winkelman (Figures 3-1 and 3-2). A detailed discussion of the indoor and attic dust data collected for the RI is presented in Section 4.6 of Volume I of the RI Report (CH2M HILL, 2008).

This task involved characterizing metal contaminants in samples of indoor dust and attic dust collected from 18 homes in Hayden and four homes in Winkelman. Indoor dust sampling was conducted on February 23, May 17, and May 18, 2006. EPA provided oversight throughout the dust sampling events.

3.6.1 Sample Location Selection

Homes were selected for sampling based on concentrations of arsenic in soil detected during residential surface soil sampling activities in January and February 2006. The sample locations were selected to generally include several homes where relatively low, medium, and high concentrations of arsenic were found in soils.

3.6.2 Sample Collection Procedures

The dust sampling method conducted was directed and judgmental. If dust was visible at specific indoor locations in a home, the dust was vacuumed to create a sample (as opposed to random or gridded sampling methods). Attic dust sampling locations were chosen as the closest accessible area to the attic access hatch that had an undisturbed accumulation of dust, which was sampled using a brush or putty knife. Some locations did not include attic

dust sampling because the home either did not have an attic or the attic was not easily accessible.

3.6.2.1 Indoor Dust

The indoor (occupied area) dust samples were collected from floors and other horizontal surfaces at all 22 homes, with preference given to areas that tend to collect dust (such as high window ledges, along baseboards, and behind furniture). A fundamental assumption of this screening evaluation is that the dust from these locations is representative (in terms of chemical concentrations) of the dust that a household resident would be exposed to. Dust was collected from surfaces by means of a hand-held vacuum cleaner device.

3.6.2.2 Attic Dust

Attic dust samples were collected at all residences where attics were accessible (11 of the 22 homes). A ladder was placed under the attic entrance to allow access to the attic for dust sampling. Each sampling location chosen was the closest accessible area to the access hatch that had an undisturbed accumulation of dust. Attic dust was collected from the surfaces surrounding the sampling location using a brush or putty knife.

3.6.3 Selection of Chemicals of Concern for Dust

Based on the soil COCs, arsenic, copper, and lead were selected as COCs for dust. Limited exceedances of the Arizona R-SRLs were observed for metals other than arsenic, copper, and lead in dust samples. The following results are based on the data tabulated in Table 3-3:

- **Cadmium:** Cadmium concentrations in three dust samples exceeded the Arizona R-SRL of 38 mg/kg. These included Parcel 101-07-029 in Zone 10 at 85.7 mg/kg (indoor); Parcel 101-07-061 in Zone 9 at 51.4 mg/kg (attic only); and Parcel 101-07-111 in Zone 6 at 465 mg/kg (indoor). The Zone 6 concentration is notably elevated compared to other cadmium detections.
- **Aluminum, Antimony and Vanadium:** In one Hayden indoor dust sample (Parcel 101-07-111 in Zone 6), the aluminum concentration of 173,000 mg/kg exceeded the Arizona R-SRL of 76,000 mg/kg; the antimony concentration of 37 mg/kg exceeded the Arizona R-SRL of 31 mg/kg; and the vanadium concentration of 84 mg/kg exceeded the Arizona R-SRL of 78 mg/kg.
- **Zinc:** In one indoor dust sample (Parcel 101-09-111B in Zone 16), the zinc concentration of 28,400 mg/kg exceeded the Arizona R-SRL of 23,000 mg/kg.

Table 3-3 presents the dust sample results for metals other than arsenic, copper, and lead that exceeded screening-levels and the corresponding soil sample results. None of the soil concentrations for these metals exceeded the respective Arizona R-SRL. Although based on the results of just one surface soil sample per parcel, this comparison suggests that the high concentrations of cadmium, aluminum, antimony, vanadium, and zinc found in the dust samples are relatively limited in extent and may not be related to the contamination in soil.

4. Exposure Assessment

Exposure assessment is the determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure. Exposure assessments may consider past, present, and future exposures, using varying assessment techniques for each phase. The objective of the exposure assessment is to estimate the type and magnitude of exposures to COCs that are present at or migrating from a site.

The three primary steps in exposure assessment are identification of exposed populations, identification of exposure pathways, and quantification of exposure. A CSM is a tool used to assist with the identification of potential exposure media, human receptors and exposure pathways. The CSM, summarized in Figure 2-1, indicates complete and potentially complete exposure pathways under current and reasonably likely future conditions. An exposure pathway is defined as complete when each of the five elements of a complete pathway is present:

- A source of contaminants (e.g., smelter)
- A release mechanism (e.g., stack emissions)
 - A secondary source (e.g., off-facility soil)
 - A secondary release mechanism (e.g., soil adhering to shoes)
- An exposure medium (e.g., soil, indoor dust)
- A route of exposure (e.g., incidental ingestion, direct contact)
- A receptor (e.g., residents of Hayden and Winkelman)

The major environmental media associated with residential exposures to site-related releases are expected to be soil and air. For that reason, the risks and hazards associated with exposure to residential soil and ambient air are the major focus of this HHRA. The CSM shown in Figure 2-1 identifies the exposure pathways of concern.

4.1 Exposure Point Concentrations

Chemical EPCs for the COCs are used within the exposure assessment calculations to estimate potential chemical intake. For example, surface soil EPCs were calculated for each residential parcel or non-residential exposure area that was sampled.

EPC estimates do not include physical, chemical, or biological processes that could result in the reduction of chemical concentrations over time. The EPCs are assumed to remain constant at levels reflected in the analytical results. This general assumption of steady-state conditions also applies to sources and contaminant-release mechanisms. This assumption may result in a conservative evaluation of long-term exposure conditions.

The measure of exposure appropriate for a risk assessment is the average concentration of a contaminant throughout an area to which humans are exposed. The exposure area concept is based on the assumption that over a long enough period of time, a receptor would contact all parts of the exposure area. A conservative estimate of the average concentration of a chemical across an exposure area is the 95 percent UCL; 95 percent UCLs were calculated

for each data set using ProUCL4 software (EPA, 2006a; EPA, 2007a). Version 4 of ProUCL offers new approaches for calculating UCLs of the mean, particularly when non-detects are present. These new approaches consider a large variety of inputs including the perceived distribution of the detected results (if no perceived distribution is acceptable, non-parametric alternatives are offered), sample size, variability, and skewness.

The ProUCL decision tree for UCLs of the mean is very large, with parametric approaches with non-detects centering on maximum likelihood estimates for use as proxy substitutions. These estimates attempt to complete the censored left tail of the data using information available from the available detected data. The distributions available in ProUCL include normal, lognormal, and gamma distributions.

Non-parametric approaches are available when a discernable distribution cannot be identified. When non-detects are present, the primary non-parametric approach involves the Kaplan-Meier approach. Depending on the data, the Kaplan-Meier approach may be applied with aspects of a student t approach or one of various “bootstrap” approaches. When all results are detected, other non-parametric approaches (i.e., the Chebyshev approach) are used.

4.2 Estimation of Chemical Intake

Exposure (or intake) is defined as contact between a receptor and a chemical. Intake is normalized for time and body weight and is expressed as milligrams (of chemical) per kilogram (of body weight) per day (mg/kg-day). Six basic factors are used to estimate intake: chemical concentration, contact rate, exposure frequency (EF), exposure duration (ED), body weight, and averaging time.

Intake can be described by the following general equation:

$$\text{Intake} = \frac{\text{Concentration} \times \text{ContactRate} \times \text{ExposureFrequency} \times \text{ExposureDuration}}{\text{BodyWeight} \times \text{AveragingTime}}$$

The intake of chemicals evaluated for non-carcinogenic health effects is estimated over an averaging time equal to the duration of assumed exposure or average daily dose (ADD). The intake of a chemical evaluated for carcinogenic health effects is referred to as the lifetime average chemical intake or lifetime average daily dose (LADD). The LADD is calculated by prorating the total cumulative dose of the chemical over an entire life span (assumed to be 70 years). The selection of an averaging time that spans a lifetime is based on EPA guidance: “The approach for carcinogens is based on the assumption that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime” (EPA, 1989).

Quantification of exposure includes evaluation of exposure parameters that describe the exposed population (e.g., contact rate, exposure frequency and duration, and body weight). Each exposure parameter in the equation has a range of values. The reasonable maximum exposure (RME) risk estimate was used in this HHRA. An RME is the “highest exposure that is reasonably expected to occur” and is estimated using a combination of average and upper-bound values of human exposure parameters (EPA, 1989).

Chemical intake is calculated by using an appropriate equation that divides exposure variables by an averaging time. For non-carcinogenic compounds, the averaging time equals the exposure duration; whereas for carcinogenic compounds, the averaging time used is a lifetime, assumed to be 70 years (EPA, 1989).

4.2.1 Residential Exposure Assumptions

The Site reconnaissance conducted by CH2M HILL on September 8, 2005, revealed that in Hayden and Winkelman, the soil around most residences is not vegetated and many residences do not have paved driveways. The residential parcels consist of the residence and bare soil.

EPA RME assumptions were used for the EF for the residential scenario (i.e., 350 days per year [EPA, 1991a]). Based on the common assumption that workers take two weeks of vacation per year, EPA assumes that a resident will be away from home approximately 15 days per year. For the residential scenario (i.e., 30 years [EPA, 1989]), a 30-year residential ED was assumed, consisting of six years as a child and 24 years as an adult. The residential soil exposure assumptions used to estimate exposures are presented in Table 4-1.

4.2.2 Non-Residential Exposure Assumptions

Site-specific assumptions were used for EF, ED, and exposure time for the exposure to non-residential areas. These site-specific exposure assumptions are based on professional judgment made by EPA and CH2M HILL project personnel and an interview with a Winkelman resident about exposure-related activities of potential receptors in these areas (Hillenbrand, 2008). Interview notes are included in Appendix I. Exposure assumptions are presented in Table 4-2.

For non-residential exposure scenarios, three types of receptors were evaluated based on the differences in level of exposure in different areas and activities that receptors may engage in. A list of areas associated with each type of receptor is presented in Table 4-3. The three types of receptors include:

- In-town trespasser
- Remote trespasser
- Recreational user (includes bike-riding youth, golfer, hiking adult, etc.)

An adult and an eight-year old youth were evaluated for both types of trespassers. A body weight of 70 kilograms (kg) is assumed for an adult (EPA, 1991a) and 28 kg for a child, assuming the mean body weight of an eight-year old child (EPA, 2006c).

The exposure areas located near or adjacent to housing, including the ASARCO Properties, are evaluated using in-town trespasser exposure assumptions. For the in-town trespasser, a site-specific EF of 250 days per year was used. This assumes that the trespasser may be exposed to these soils located in town five days per week for 50 weeks per year. A 30-year exposure duration was assumed for the in-town trespassers, including six years as a child and 24 years as an adult. For exposure time, site-specific assumptions of 0.5 hour per day for an adult trespasser and one hour per day for a child trespasser were assumed for the

inhalation exposure route. The exposure time assumption was based on an adult walking through some of these areas on their way to work, etc., or a youth bicycling in these areas.

The exposure areas more distant from housing in the Outlying Areas are evaluated for exposure by a remote trespasser. For the remote trespasser, a site-specific EF of 12 days per year for an adult and 150 days per year for a child was used. This assumes that an adult trespasser is exposed to soil in areas further away from town once a month, and a child trespasser is exposed to these soils three times a week for 50 weeks per year. A 30-year ED was assumed for the remote trespassers, including six years as a child and 24 years as an adult. A site-specific exposure time of two hours per day was assumed for the inhalation exposure route.

For the recreational user, a site-specific EF of 50 days per year for an adult and 350 days per year for a child was used. This assumes that a child is exposed to soil at the school yard/park 350 days per year. The EF of 350 days per year was applied to both the school child and park user as a conservative assumption, based on an assumption that children may sometimes play in these large, open areas as often as they use their own backyards. An adult is assumed to be exposed to soil at the park/golf course 50 days per year (once a week for 50 weeks per year). For ED, a site-specific ED of eight years was assumed for a child and 24 years for an adult. For exposure time, site-specific values of four hours per day for an adult at the golf course/park, six hours per day for a child at the school yard (includes exposure before school, at recess, during lunch, and during after school playground time), and two hours per day for a child at the park were assumed for the inhalation exposure route.

People may not live year-round in WSC Parcel A, Parcel B, and Parcel C. However, as a conservative estimate of risk or hazard, a residential exposure scenario was used for risk assessment. Residential exposure assumptions described in Section 4.2.1 were used for these three properties.

4.2.3 Soil

The primary exposure routes include incidental ingestion and dermal contact with soil, and inhalation of airborne dust particulates suspended from the soil.

4.2.3.1 Incidental Ingestion

Adult and child residents and trespassers may be exposed to COCs in soil (residential and non-residential) through incidental ingestion. Children will inadvertently ingest soil/dust as part of their normal mouthing behavior, especially children younger than six years old (EPA, 1989). Inadvertent soil/sediment/dust ingestion also will occur through the consumption of food held in unwashed hands. Soil ingestion rates used for adults and children for the residential scenarios are 100 milligrams per day (mg/day) for adults and 200 mg/day for children (EPA, 1991a).

For each scenario, chemical intake from soil ingestion is estimated using the following equation:

$$I = \frac{Cs \times BAF \times IR \times EF \times ED \times 10^{-6} \text{ kg / mg} \times CF - 1}{BW \times AT}$$

Where:

I	=	Chemical intake (mg/kg body weight/day)
Cs	=	Chemical concentration in soil (mg/kg)
BAF	=	Bioavailability factor (fraction, unitless)
IR	=	Ingestion rate (mg/day)
EF	=	Exposure frequency (days/years)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF_1	=	Conversion factor (2.74 x 10 ⁻³ years/day)

A site-specific bioavailability factor was used for ingestion of arsenic in soil. A bioavailability factor of 0.8 was used for arsenic based on the results of mineralogy speciation.

4.2.3.2 Dermal Contact

Dermal absorption from soil is a function of the concentration of the chemical, the amount of soil in contact with the skin, the amount of exposed skin, the duration and frequency of the contact, and the type of chemical. Chemical intake from dermal contact is estimated using the following equation:

$$I = \frac{C_s \times ABS \times SA \times AF \times EF \times ED \times 10^{-6} \text{ kg / mg} \times CF_{-1}}{BW \times AT}$$

Where:

I	=	Chemical intake (mg/kg body weight-day)
Cs	=	Chemical concentration in soil (mg/kg)
SA	=	Surface area (square centimeters [cm ² /day])
ABS	=	Absorption factor (fraction)
AF	=	Adherence factor - soil to skin (milligrams per square centimeter per day [mg/cm ²])
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF_1	=	Conversion factor (2.74 x 10 ⁻³ years/day)

For contact with soil in the RME residential scenario, a skin surface area of 5,700 cm² was assumed for adults and 2,800 cm² for children (EPA, 2004a). For the non-residential scenario for a child, 3,000 cm² was assumed for the eight-year old youth.

The RME values for soil adherence, which is the amount of soil that can directly contact the skin, were assumed to be 0.2 mg/cm² for children and 0.07 mg/cm² for adults for both residential and non-residential scenarios (EPA, 2004a).

In addition to factors influencing the amount of soil contact with the skin, numerous factors control the dermal absorption process. Dermal absorption factors were obtained from EPA (EPA, 2004a).

4.2.3.3 Inhalation of Airborne Particulates

Adult and child residential and trespasser receptors may potentially be exposed to COCs in soil via inhalation of airborne particulate matter. For each scenario, chemical intake from particulate inhalation was estimated using the following equation:

$$I = \frac{C_s \times InR \times EF \times ED \times (1/PEF) \times CF_{-1}}{BW \times AT}$$

Where:

I	=	Chemical intake (mg/kg body weight-day)
C _s	=	Chemical concentration in soil (mg/kg)
InR	=	Inhalation rate (cubic meters per day [m ³ /day])
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
PEF	=	Particulate emission factor (cubic meters per kilogram [m ³ /kg])
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF ₋₁	=	Conversion factor (2.74 × 10 ⁻³ years/day)

A particulate emission factor (PEF) is used to relate the concentration of a contaminant in soil to the concentration of dust particles in air. A value of 1.3 × 10⁹ m³/kg was used for the PEF (EPA, 2004a).

4.2.4 Ambient Air

In addition to evaluating the inhalation exposure route using modeled air concentrations from soil as described above (i.e., using the PEF), chemical intake from ambient air was evaluated using ambient air monitoring data. For each scenario, chemical intake from ambient air inhalation was estimated using the following equation:

$$I = \frac{C_a \times InR \times EF \times ED \times CF_{-1}}{BW \times AT \times CF_{-2}}$$

Where:

I	=	Chemical intake (mg/kg body weight-day)
C _a	=	Chemical concentration in ambient air (µg/m ³)
InR	=	Inhalation rate (m ³ /day)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (years)

- CF_1 = Conversion factor (2.74×10^{-3} years/day)
 CF_2 = Conversion factor (1,000 micrograms per milligram [$\mu\text{g}/\text{mg}$])

4.2.5 Groundwater

Residential exposure was assumed for the quantitative screening-level evaluation applied to the groundwater data. For this screening-level evaluation, the “risk ratio” approach was used; in this approach, the concentrations of chemicals or radionuclides in groundwater are compared to EPA Region 9 PRGs. Section 6.2 provides the details of this screening-level approach. For the residential scenario, it was assumed that an adult ingests two liters of water per day and a child ingests one liter of water per day. The assumptions for EF, ED, and body weight are the same as for residential exposure to soil as discussed in Section 4.2.1 above. The assumed skin surface area for the groundwater pathway differs from exposure to soil because the exposure to groundwater is a bathing or showering scenario that includes the whole body (no protection from clothing). Therefore, the assumed body surface area is the total amount of skin surface that can be exposed to contaminated groundwater. The resident is assumed to be exposed for a bathing scenario. The recommended exposed skin surface area is the total body surface area, which is 18,000 cm² for an adult and 12,000 cm² for a child (EPA, 1991a).

4.2.6 Surface Water

Site-specific assumptions were used for the recreational scenario. An EF of 33 days per year was used, which assumes that the child and/or adult recreational user swims in surface water two days per week from June to September. A 30-year ED was assumed, consisting of six years as a child and 24 years as an adult. The adult and child recreational exposure assumptions for surface water used to estimate exposures in this HHRA are presented in Table 4-2.

4.2.6.1 Intake from Surface Water Ingestion

Adult and child recreational users may be exposed to COCs in surface water through incidental ingestion. The surface water incidental ingestion rate used for adults and children for the recreation scenarios is 50 milliliters per hour (ml/hr) of swimming (EPA, 1989).

For each scenario, chemical intake from surface water ingestion is estimated using the following equation:

$$I = \frac{C_w \times IR \times ET \times EF \times ED \times CF_1 \times CF_2 \times CF_3}{BW \times AT}$$

- I = Chemical intake (mg/kg body weight/day)
 C_w = Chemical concentration in surface water ($\mu\text{g}/\text{L}$)
 IR = Ingestion rate (ml/hr)
 ET = Exposure time (hours/day)
 EF = Exposure frequency (days/years)
 ED = Exposure duration (years)
 BW = Body weight (kg)

AT	=	Averaging time (years)
CF_1	=	Conversion factor (2.74×10^{-3} years/day)
CF_2	=	Conversion factor (1×10^{-3} milligrams per kilogram [mg/ μ g])
CF_3	=	Conversion factor (1×10^{-3} liters per milliliter [L/ml])

Exposure time is the amount of time for which a recreational user (swimmer) is exposed to surface water. Exposure time of 2.6 hours per day was assumed for this exposure scenario, which is based on the national average for swimming time (EPA, 1989).

4.2.6.2 Intake from Dermal Contact with Surface Water

Dermal absorption from surface water is a function of the absorbed dose of chemical per event of contact with the skin, the exposed skin surface area, the duration and frequency of the contact, and the type of chemical. Chemical intake from dermal contact is estimated using the following equation:

$$I = \frac{DA_{event} \times EV \times EF \times ED \times SA \times CF_{-1}}{BW \times AT}$$

Where:

I	=	Chemical intake (mg/kg body weight/day)
DA _{event}	=	Absorbed dose of chemical per event (mg/cm ² -event)
EV	=	Number of exposure events per day (event/day)
EF	=	Exposure frequency (days/years)
ED	=	Exposure duration (years)
SA	=	Surface area (cm ²)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF_1	=	Conversion factor (2.74×10^{-3} years/day)

Exposure assumptions used in the intake calculations for the dermal contact with surface water include body surface area and absorbed dose per exposure event per area of skin exposed (Appendix E). These parameters are presented below:

- **Skin Surface Area:** The body surface area is the total amount of skin surface that can be exposed to contaminated surface water. The recreational user is assumed to be exposed for a swimming scenario. The recommended exposed skin surface area is the total body surface area, which is 18,000 cm² for an adult and 12,000 cm² for a child (EPA, 2006c).
- **Absorbed Dose per Event (DA_{event}):** The absorbed dose of a chemical per event of exposure is the total estimated dose dissolved in the skin at the end of exposure (EPA, 2004a). A chemical-specific DA_{event} (milligrams per cubic centimeter [mg/cm³]-event) is applied. For inorganic chemical compounds, the DA_{event} is:

$$DA_{event} = K_p \times C_w \times t_{event}$$

Where:

K _p	=	Permeability coefficient
C _w	=	Chemical concentration in surface water (mg/cm ³)
t _{event}	=	Exposure time (hours)

4.2.7 Sediment

Site-specific assumptions were used for recreational scenario (an adult and child angler). An EF of 100 days per year was used, which assumes that the child and/or adult angler is exposed to the sediment two days per week year round (every weekend). A 30-year ED was assumed, consisting of six years as a child and 24 years as an adult. The adult and child recreational exposure assumptions for sediment used to estimate exposures in this HHRA are presented in Table 4-2.

4.2.7.1 Ingestion

Adult and child anglers may be exposed to COCs in sediment through incidental ingestion. Children inadvertently ingest sediment/soil as part of their normal mouthing behavior, especially children younger than six years old (EPA, 1989). Inadvertent soil/sediment/dust ingestion also occurs through the consumption of food held in unwashed hands. Soil ingestion rates of 100 mg/day for adults and 200 mg/day for children were used, which are soil ingestion rates for recreational scenarios (EPA, 1991b).

For the recreational scenario, chemical intake from sediment ingestion is estimated using the following equation:

$$I = \frac{C_s \times BAF \times IR \times EF \times ED \times CF_{-1} \times CF_{-2}}{BW \times AT}$$

Where:

I	=	Chemical intake (mg/kg body weight/day)
C _s	=	Chemical concentration in sediment (mg/kg)
BAF	=	Bioavailability factor (fraction, unitless)
IR	=	Ingestion rate (mg/day)
EF	=	Exposure frequency (days/years)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF ₋₁	=	Conversion factor (2.74 × 10 ⁻³ years/day)
CF ₋₂	=	Conversion factor (10 ⁻⁶ kilograms per milligram [kg/mg])

A site-specific bioavailability factor for soil was used for ingestion of arsenic in sediment. A bioavailability factor of 0.8 was used for arsenic based on the results of mineralogy speciation. Section 6.1 provides details on the derivation of the site-specific bioavailability factor.

4.2.7.2 Dermal Contact

Dermal absorption from sediment is a function of the concentration of the chemical, the amount of sediment in contact with the skin, the amount of exposed skin, the duration and frequency of the contact, and the type of chemical. Chemical intake from dermal contact is estimated using the following equation:

$$I = \frac{C_s \times ABS \times SA \times AF \times EF \times ED \times CF_1 \times CF_2}{BW \times AT}$$

Where:

I	=	Chemical intake (mg/kg body weight-day)
C _s	=	Chemical concentration in soil (mg/kg)
SA	=	Surface area (cm ² /day)
ABS	=	Absorption factor (fraction)
AF	=	Adherence factor - soil to skin (mg/cm ²)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (years)
BW	=	Body weight (kg)
AT	=	Averaging time (years)
CF ₁	=	Conversion factor (2.74 × 10 ⁻³ years/day)
CF ₂	=	Conversion factor (10 ⁻⁶ kg/mg)

For contact with sediment in the RME recreational scenario, a skin surface area of 5,700 cm²/day was assumed for the adult angler and 3,000 cm²/day for the child angler (EPA, 2004a). The skin surface area for a child is based on 25 percent of the total skin surface area for an eight-year old child (12,000 cm²/day) (EPA, 2004a; EPA 2006c).

The RME values for soil/sediment adherence, which are the amount of soil/sediment that can directly contact the skin, were assumed to be 0.2 mg/cm² for children and 0.07 mg/cm² for adults (EPA, 2004a).

In addition to factors influencing the amount of sediment contact with the skin, numerous factors control the dermal absorption process. Dermal absorption factors were obtained from EPA (EPA, 2004a).

5. Toxicity Assessment

The purpose of the toxicity assessment is to weigh available evidence regarding the potential for particular contaminants to cause adverse health effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. EPA has performed the toxicity assessment step for numerous chemicals and has made available the resulting toxicity information and toxicity values, which have undergone extensive peer review. The derivation of toxicity values is a complex process that includes the evaluation of many factors relating to toxicological data, including the type of exposure route, duration of exposure, dose administered, physiology of the species tested, and the type of adverse health effect observed. In the toxicity assessment step, toxicity values are compiled that characterize potential adverse health effects from exposure to COCs. The toxicity assessment consists of two components:

1. **Hazard identification:** The process of determining what adverse human health effects, if any, could result from exposure to a particular chemical.
2. **Dose-response evaluation:** A quantitative examination of the relationship between the level of exposure and the probability of adverse health effects in an exposed population.

5.1 Hazard Identification

Cancer and non-cancer effects are evaluated differently within the toxicity assessment process. The division is based on the different mechanisms of action associated with each category. Chemicals with non-cancer effects may have cancer effects as well. These chemicals are assessed in both categories.

5.1.1 Non-Cancer Effects

For many non-carcinogenic effects, protective mechanisms are believed to exist that must be overcome before the adverse effect is manifested. A reference dose, or RfD, is the toxicity value used most often in evaluating non-cancer effects. Because variability exists in the human population, attempts are made to identify a sub-threshold level protective of sensitive individuals in the population. For most chemicals, this level can only be estimated.

Non-cancer or systemic effects are assumed to occur only after a finite level of exposure (i.e., toxic threshold) is exceeded. Exposure levels below the threshold can be tolerated by the organisms without causing an adverse health effect. Non-cancer health effects include a variety of toxicological endpoints and may include effects on specific organs or systems, such as the kidney (nephrotoxicants), the liver (hepatotoxicants), the nervous system (neurotoxicants), and the lungs (pulmonary toxicants).

Non-cancer health effects fall into two basic categories: acute effects and chronic effects. Acute toxicological effects typically occur after a short exposure, and the effects are usually observed within one to seven days. Chronic toxicological effects usually occur after repeated exposure and are observed weeks, months, or years after the initial exposure.

5.1.2 Cancer Effects

Carcinogenic effects (carcinogenesis), unlike many non-carcinogenic health effects, are thought to be a phenomenon for which risk evaluation based on presumption of a threshold is inappropriate. For carcinogens, EPA assumes that a small number of molecular events can evoke changes in a single cell that can eventually lead to uncontrolled cellular proliferation and eventually to a clinical state of disease. This hypothesized mechanism for carcinogenesis is referred to as “non-threshold,” because there is assumed to be essentially no level of exposure that does not pose a finite probability, however small, of generating a carcinogenic response.

EPA has developed a carcinogen-classification system that uses a weight-of-evidence approach to classify the likelihood of a chemical being a human carcinogen. Information considered in developing the classification includes human studies that associate cancer incidence with exposure. Also considered are long-term animal studies under controlled laboratory conditions. Other supporting evidence considered includes short-term tests for genotoxicity, metabolic, and pharmacokinetic properties; toxicological effects other than cancer; structure-activity relationships; and physical and chemical properties of the chemical.

5.2 Dose-Response Evaluation

Toxicity values used in HHRAs are quantitative expressions of the dose-response relationship for a chemical. These values are expressed as cancer slope factors (CSFs) and non-cancer RfDs, both of which are specific to the route of exposure. Uncertainty and modifying factors are commonly applied to toxicity values in order to account for uncertainties inherent in the process of relating laboratory toxicity data to relevant human exposure levels.

The human health toxicity values used to develop this HHRA were obtained from the following EPA hierarchy of sources as presented in the Office of Solid Waste and Emergency Response (OSWER) Directive 9285.7-53 (EPA, 2003):

- Tier 1 – EPA’s Integrated Risk Information System (IRIS)
- Tier 2 – EPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs)
- Tier 3 – Additional EPA sources (e.g., historic Health Effects Assessment Summary Table (HEAST) and National Center for Environmental Assessment [NCEA] provisional values) and non-EPA sources of toxicity information (e.g., Cal-EPA toxicity values)

5.2.1 Toxicity Values for Non-Cancer Effects

The toxicity value used to describe the dose-response relationship for non-cancer health effects is the RfD. EPA (1989) defines the RfD as “an estimate (with uncertainty spanning perhaps an order-of-magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.”

The oral RfD is generally expressed in units of mg/kg-day. RfDs for effects associated with inhalation of a particular chemical are given as a reference concentration (RfC) ($\mu\text{g}/\text{m}^3$) that can be converted to an intake (RfD) in terms of mg/kg-day.

The chronic RfD for arsenic is 0.0003 mg/kg-day for the ingestion pathway as provided by IRIS. This chronic RfD is based on human chronic oral exposure. The critical effect observed was hyperpigmentation, keratosis, and possible vascular complications (EPA, 2008a). An inhalation RfD is not available for arsenic.

The chronic oral RfD for copper is 0.04 mg/kg/day (EPA, 1997), based on human exposure. The critical effect is gastrointestinal irritation (EPA, 1997). An inhalation RfD is not available for copper.

5.2.2 Toxicity Values for Cancer Effects

For practical reasons, a cancer risk at low-exposure levels is difficult to measure directly either by animal experiments or epidemiological studies. Current EPA guidelines recommend using a linearized multistage model for carcinogenicity, when appropriate, to extrapolate from the relatively high doses administered to experimental animals (or exposure noted in human epidemiological studies) to lower exposure levels expected for human contact in the environment (EPA, 1986). The model assumes that if a carcinogenic response occurs at the dose levels used in the animal or epidemiological study, a response will occur at all lower doses.

There is uncertainty and conservatism built into the risk-extrapolation approach. Cancer risks estimated by this method produce an estimate that provides a plausible upper limit of risk (i.e., it is not likely that the true risk would be much more than the estimated risk, but could be considerably lower) (EPA, 1989).

The dose-response relationship for cancer effects is usually expressed as a CSF. Generally, the CSF is a plausible upper-bound estimate of the probability (risk) of a carcinogenic response per unit intake of a chemical over a lifetime. The CSF is usually the 95 percent UCL of the slope of the dose-response curve and is expressed as the inverse of mg/kg-day.

Arsenic is considered to be a human carcinogen based on sufficient evidence from human data. Increased mortality from multiple internal organ cancers (liver, kidney, lung, and bladder) and an increased incidence of skin cancer were observed in populations consuming drinking water high in inorganic arsenic. IRIS provides an oral CSF for arsenic of $1.5 (\text{mg}/\text{kg}\text{-day})^{-1}$ for ingestion. Increased lung cancer mortality was observed in multiple human populations exposed primarily through inhalation. The inhalation CSF is $15 (\text{mg}/\text{kg}\text{-day})^{-1}$ (EPA, 2008a).

Chromium (VI) is considered a known/likely human carcinogen by the inhalation route. Inhalation occupational exposure is associated with human lung cancer. The inhalation CSF for total chromium (1:6 ratio Cr VI: Cr III) is $42 (\text{mg}/\text{kg}\text{-day})^{-1}$ (EPA, 2004b).

Cadmium is considered a probable human carcinogen based on limited carcinogenicity data for humans. Limited evidence from occupational epidemiologic studies of cadmium is consistent across investigations and study populations. The inhalation CSF for cadmium is $6.3 (\text{mg}/\text{kg}\text{-day})^{-1}$ (EPA, 2008a).

5.2.3 Toxicity Assessment for Lead

Intake of lead is assessed differently than intake for other chemicals. Currently, EPA has not established CSFs or RfDs for lead. Some data suggest that no threshold for lead toxicity exists (ATSDR, 2007a). Much of the toxicological data collected on the effects of lead on the human body relate exposure and effect in terms of the amount of lead in blood associated with an observed effect, expressed as micrograms of lead per deciliter of blood ($\mu\text{g lead/dL blood}$). EPA and the Centers for Disease Control and Prevention (CDC) have identified childhood blood levels of $10 \mu\text{g/dL}$ as the level of concern above which significant health risks may occur (EPA, 2003).

Exposure to lead in soil was evaluated using the California Department of Toxic Substances Control (DTSC) Lead Risk Assessment Spreadsheet, LeadSpread Version 7 (DTSC, 2000). This model calculates a screening-level that represents a concentration of lead in soil for children that is protective for a combined exposure to lead in air, drinking water, food, and soil. For the residential lead screening, the most conservative (health-protective) screening-level available from the LeadSpread model was selected (99th percentile) based on protection of children's health.

The Site-specific residential lead screening-levels are 122 mg/kg , including ingestion of homegrown produce, and 212 mg/kg excluding ingestion of homegrown produce, using the local concentration for lead in ambient (outdoor) air and drinking water supply. The ambient air concentration used in the LeadSpread model to produce the soil screening value is the second highest lead concentration detected in air from the two RI air monitoring stations. On November 21, 2006, at the Hayden Station, lead was detected at $0.5947 \mu\text{g/m}^3$. The maximum concentration was not used since it occurred after the screening values were established (concentration of $0.8262 \mu\text{g/m}^3$ on September 11, 2007). The maximum groundwater concentration detected from the two groundwater monitoring events was from a sample in the Winkelman well field. Lead was detected at $8.2 \mu\text{g/L}$ from WM-4 on March 3, 2006. The results of LeadSpread modeling using Site-specific data are included in Appendix A.

The EPA NAAQS for lead was used for comparison to Site lead air data. The NAAQS for lead is $1.5 \mu\text{g/m}^3$ (quarterly average). NAAQS are promulgated by EPA to meet requirements set forth in Sections 108 and 109 of the federal Clean Air Act. Those two Clean Air Act sections require the EPA Administrator to (1) list widespread air pollutants that reasonably may be expected to endanger public health or welfare; (2) issue air quality criteria for them that assess the latest available scientific information on nature and effects of ambient exposure to them; (3) set "primary" NAAQS to protect human health with adequate margin of safety and to set "secondary" NAAQS to protect against welfare effects (e.g., effects on vegetation, ecosystems, visibility, climate, manmade materials, etc.); and (5) periodically review and revise, as appropriate, the criteria and NAAQS for a given listed pollutant or class of pollutants (EPA, 2006b).

On November 1, 2007, the EPA's Office of Air Quality Planning and Standards released the final Staff Paper and final Human Exposure and Health Risk Assessment for lead (EPA, 2007b and 2007c). The Staff Paper recommended that EPA strengthen the existing lead standards to improve public health protection. It recommended consideration of a range of levels, from levels that are currently seen in many urban areas across the United States (approximately 0.1 to $0.2 \mu\text{g/m}^3$) to the lowest levels evaluated in the Exposure and Health

Risk Assessment (0.02 to 0.05 $\mu\text{g}/\text{m}^3$). This recommendation is based on the following key observations:

- Lead in the air contributes to lead in blood via inhalation and via ingestion of lead deposited from the air (e.g., from soil and indoor dust).
- A large body of new scientific studies shows that adverse effects in young children occur at much lower blood lead levels than was understood when the current standard was set in 1978.
- The current evidence demonstrates the occurrence of a variety of adverse health effects associated with lead, including those on the developing nervous system. IQ loss in children was the key health effect addressed in the Staff Paper.

On May 20, 2008, EPA announced their proposal to revise the NAAQS for lead in the *Federal Register* (EPA, 2008d). In that announcement, EPA proposes to revise the level to within the range of 0.10 to 0.30 $\mu\text{g}/\text{m}^3$. The comment period for this proposed rule is through July 21, 2008. Consistent with the terms of a court order, the Administrator will sign a notice of final rulemaking for publication in the *Federal Register* by September 15, 2008.

5.2.4 Chemicals Not Evaluated

Chemicals without EPA tap water PRG concentrations are discussed qualitatively in Section 7, Uncertainty Analysis. Essential nutrients (i.e., calcium, magnesium, potassium, iron, and sodium) were not quantitatively evaluated in this HHRA since they are not associated with toxicity in humans under normal circumstances.

6. Risk Characterization

In this risk characterization step, quantification of cancer risks and non-cancer hazards is accomplished by combining the results of the exposure assessment (estimated chemical intakes) with the results of the dose-response assessment (toxicity factors established in the toxicity assessment) to provide numerical estimates of potential health effects. The quantification approach differs for potential non-cancer and cancer effects, as described in the following subsections. Another important factor in characterizing risks and hazards for metals is the percentage of a particular metal in soil that is available for human uptake, referred to as bioavailability. Details related to the bioavailability of arsenic and lead are provided in Section 6.1. The critical uncertainties associated with the risk calculations are discussed in Section 7.

In the risk characterization, theoretical non-cancer hazards and theoretical excess lifetime cancer risks (ELCRs) associated with exposure to chemicals are estimated. Theoretical hazards for non-carcinogenic (i.e., not cancer-causing) chemicals at a site are evaluated by comparison to a non-cancer threshold of 1 (unity). To evaluate cancer effects, EPA considers a risk management range of 10^{-6} to 10^{-4} to be “safe and protective of public health” (56 Federal Register 3535), although EPA has discretion to take action in this range depending on site-specific circumstances. Even risks slightly greater than 1×10^{-4} may be considered adequately protective based on site-specific conditions, including any uncertainties about the nature and extent of contaminants and associated risks.

Although this HHRA uses RME assumptions and produces numerical estimates of risk, it should be recognized that these numbers might not predict actual health outcomes because they are based largely on hypothetical assumptions. Their purpose is to provide a frame of reference for risk management decision making. Any actual risks are likely to be lower than these estimates, and may even be zero. Interpretation of the risk estimates provided should consider the nature and weight of evidence supporting these estimates, as well as the magnitude of uncertainty surrounding them.

6.1 Bioavailability Factor for Arsenic and Lead

One example of exposure to metals in soil occurs from ingesting contaminated soil that clings to people’s hands. Not all metals swallowed, however, will enter into the body. Some metals, such as arsenic and lead, will pass through the digestive system without being absorbed. Some arsenic or lead is bound so tightly to soil particles that it is less likely to be absorbed by the lining of the intestinal tract than arsenic or lead bound loosely to soil particles. This process of how much arsenic or lead crosses the stomach and enters into the bloodstream and the body is known as bioavailability. For example, if only half the arsenic in soil is capable of passing from the gut and into an individual’s body, the soil arsenic is referred to as being 50 percent bioavailable. This is the case with arsenic in the arsenopyrite mineral form.

The bioavailability of arsenic in soil varies depending on the sources of arsenic (e.g., smelters, mines, pesticide applications). Studies have shown soil arsenic bioavailability to range from 3 to 80 percent (Roberts, 2007; Casteel, 1997; Casteel, 2001; Lorenzana, 1996).

The estimation of risk/hazard resulting from incidental ingestion of arsenic-contaminated surface soil for this HHRA, included an adjustment based on the estimated bioavailability (i.e., percentage of arsenic in soil available for human uptake). A bioavailability factor of 80 percent is used as a conservative estimate for this HHRA based on a Site-specific study of the mineralogy of soil samples.

Geochemical speciation was performed on 12 soil samples to determine the mineralogy of soil arsenic and provide some information on the potential bioavailability of arsenic in soil. Most of the arsenic found was sorbed arsenic V (arsenate), which is more bioavailable than arsenopyrite. Details of the mineralogy of the soil samples are provided in Appendix J.

The LeadSpread Version 7.0 bioavailability default of 44 percent has been applied to the lead evaluation.

6.2 Cancer Risks

ELCRs were estimated for all carcinogenic chemicals. The theoretical ELCR associated with the LADDs are calculated as the product of the LADD and the CSF for each chemical and exposure route as shown below:

$$\text{Risk} = \text{CSF} \times \text{LADD}$$

Where:

- Risk = Theoretical ELCR for chemical and exposure route
- CSF = Cancer slope factor for chemical and exposure route
- LADD = Lifetime average daily dose for chemical and exposure route

This theoretical risk is the incremental increase in the probability of developing cancer during one's lifetime in addition to the background probability of developing cancer (that is, if no exposure to site chemicals occurs). For example, a 2×10^{-6} ELCR means that, for every one million people exposed to the carcinogen throughout their lifetimes, the average incidence of cancer might increase by two cases of cancer. In the United States population, the likelihood of developing cancer over one's lifetime is approximately 1-in-2 for males and 1-in-3 for females (American Cancer Society, 2007).

Based on the EPA risk assessment guidelines for carcinogens (EPA, 1989), cancer risks from exposure via multiple exposure routes were assumed to be additive. Therefore, estimated ELCRs for all exposure routes having a common receptor were summed to yield a single estimated cancer risk for the receptor.

For assessing excess cancer risk for a 30-year residential exposure, the child (six-year exposure) and adult (24-year exposure) residential cancer risks are summed. EPA national Superfund guidance calculates lifetime risk over 70 years based on an RME scenario, which is defined as a 30-year exposure in the case of residents. The concept of lifetime risk does not automatically imply exposure over an entire 70-year lifetime.

For the groundwater samples collected at Hayden and Winkelman, screening-level risks were estimated using EPA Region 9 tap water PRGs (EPA, 2004b) and radionuclide PRGs from EPA's Oak Ridge National Laboratory (ORNL) website (2008b).

For cancer risk estimates, the location/source-specific chemical concentration in groundwater is divided by the EPA Region 9 tap water or radionuclide PRG that is based on carcinogenic effects. The resulting ratio is multiplied by 1×10^{-6} to estimate chemical specific risk for an RME. For multiple chemicals, the risks for the chemicals are separately summed to estimate total cancer risk for groundwater.

$$Risk = \frac{C_{gw}}{PRG_{ca}} \times 10^{-6}$$

Where:

C_{gw} = Chemical concentration in groundwater ($\mu\text{g/L}$)
 PRG_{ca} = EPA Region 9 PRG for cancer evaluation ($\mu\text{g/L}$)

6.3 Non-Cancer Hazards

Non-carcinogenic effects for each exposure route and chemical are evaluated by comparing the average dose over a specified time period to a chemical-specific RfD. The ratio of the ADD to the RfD is called a hazard quotient (HQ), which is calculated as follows:

$$HQ = \frac{ADD}{RfD}$$

Where:

HQ = Theoretical non cancer hazard quotient for chemical and exposure pathway
 ADD = Average daily dose (mg/kg-day) for chemical and exposure pathway
 RfD = Reference dose (mg/kg-day) for chemical and exposure pathway

The HQ assumes there is a dose below which adverse health effects are unlikely (EPA, 1989). If the ADD is below the threshold RfD (i.e., the HQ is less than 1), it is unlikely that non-carcinogenic effects would occur. To assess the overall potential for non-carcinogenic effects from a particular exposure scenario, HQs for the relevant individual soil exposure routes (i.e., ingestion, dermal contact, and inhalation) and chemicals are summed to obtain the HI for the population evaluated:

$$HI = \text{Sum of HQs for chemicals and exposure routes}$$

For assessing non-cancer hazards for a 30-year residential exposure, the child (six-year exposure) and adult (24-year exposure) residential HIs are calculated separately. A 30-year exposure scenario is consistent with EPA national guidance, as explained in the preamble to the National Contingency Plan (NCP) (55 Federal Register 8710).

An HI equal to or less than 1 indicates there is unlikely to be any increased health risk, even for sensitive populations. At the same time, an HI greater than 1 does not necessarily

indicate that adverse effects will occur, because the RfD used in the calculation contains substantial measures of conservatism. The RfD is conservative because it is typically derived by applying multiple safety factors to a level at which no adverse effects have been observed or to the lowest level at which effects have been observed in the most sensitive animal species that have been tested.

For the groundwater samples collected at Hayden and Winkelman, screening-level hazards were estimated by the risk ratio method using EPA tap water PRGs (EPA, 2004b) and radionuclide PRGs from EPA's ORNL website (2008b). For non-cancer hazard estimates, the location/source-specific chemical concentration ($\mu\text{g/L}$) in groundwater is divided by the non-cancer EPA Region 9 tap water or radionuclide PRG based on non-carcinogenic effects. For multiple contaminants, the resulting ratios (known as HQs) are separately summed for groundwater. The cumulative ratio represents a non-carcinogenic HI. An HI greater than 1 suggests further evaluation is necessary.

$$HQ = \frac{C_{gw}}{PRG_{nc}}$$

Where:

HQ	=	Hazard quotient
C_{gw}	=	Chemical concentration in groundwater ($\mu\text{g/L}$)
PRG_{nc}	=	EPA Region 9 PRG for non-cancer hazard evaluation ($\mu\text{g/L}$)

6.4 Risks/Hazards from Background Concentrations

Many substances, such as metals, are naturally occurring in the environment and are commonly present in all environmental samples. For these chemicals, it is important to determine what fraction of the concentration detected is due to the site-related contamination, and what fraction represents background for the Hayden and Winkelman areas. Background refers to the range of concentrations of the chemical in similar nearby reference areas that have not been impacted by the Site.

6.4.1 Background – Soil

Details of the background data evaluation for soil are presented in a technical memorandum (CH2M HILL, 2007), which is included in Appendix C of Volume I of the RI Report (CH2M HILL, 2008). The towns of Hayden and Winkelman are located on two different geologic settings. The soils in the Hayden area are located in the Ts geologic map unit, and the soils in Winkelman are in the Qo unit. Therefore, risk and hazard estimates for each geologic setting were prepared for comparison to the residential risks and hazards in each town. Ninety-five (95) percent UTL soil concentrations were derived for each geologic setting and were used in the background risk and hazard estimates.

Table 6-1 provides a summary of the cancer risks, non-cancer hazards, and lead concentrations compared to screening-levels for Ts and Qo background levels. Appendix H provides the summary statistics for the background data and risk calculation tables. The ELCR estimate for exposure of the Hayden resident (representing six years as a child and 24 years as an adult) to Ts background levels is 3×10^{-5} . Because arsenic is the only

carcinogenic COC evaluated, all of the risk is due to arsenic. The HI for a child resident exposed to background levels of arsenic and copper in soil is 0.9, which does not exceed the non-cancer threshold of 1.

For the Winkelman resident, the ELCR estimate is 2×10^{-5} , due to exposure to Qo background levels of arsenic in soil. The HI for a child resident exposed to Qo background levels of arsenic and copper in soil is 0.6.

The UTL values calculated from the lead background data set are 47.9 mg/kg for Ts (Hayden) and 45.8 mg/kg for Qo (Winkelman). These levels are well below the site-specific screening-level for lead of 122 mg/kg and the Arizona R-SRL of 400 mg/kg.

6.4.2 Background – Air

Air samples were not specifically collected for background purposes during the RI. However, data from several of EPA's IMPROVE network monitoring sites were evaluated to represent background levels. Data from the IMPROVE Organ Pipe Station collected during the period from January 2006 through December 2006, were selected to best represent background conditions for comparison to the Hayden and Winkelman risks associated with exposure to air impacted by the Site. Arsenic and cadmium were not detected in any of the 15 Organ Pipe air samples used for the background data set. Therefore, the EPCs used in the background risk calculation for those metals were based on an average of the MDLs.

The background 95 percent UCL concentration for lead of $0.00164 \mu\text{g}/\text{m}^3$ is much less than the NAAQS of $1.5 \mu\text{g}/\text{m}^3$ (quarterly average). The background 95 percent UCL concentration for copper is $0.0028 \mu\text{g}/\text{m}^3$. Applicable ambient air screening criteria are not available for copper.

Table 6-2 provides a summary of the residential cancer risks estimated for exposure to background levels of COCs in air. Appendix H provides the summary statistics for the background data and risk calculation tables. For residential exposure, the ELCR estimate is 6×10^{-6} for exposure to background arsenic and chromium in air. No inhalation RfDs are available for arsenic, cadmium, chromium, copper, or lead; therefore, non-cancer effects were not evaluated for the air exposure pathway.

6.4.3 Background – Other Media

Risk and hazards from background levels were not calculated for groundwater, surface water, or sediment. Site-specific background levels were not established for groundwater since upgradient monitoring wells do not exist at the Site, and were not installed during the RI. Therefore, the Site groundwater concentrations were compared with arsenic and radionuclide levels found in groundwater from an unaffected area of Maricopa County, Arizona (United States Geological Survey [USGS], 2008). For radionuclides in groundwater, national background levels (USGS, 1998) were compared with site radionuclide levels. For surface water and sediment, three samples for each media were collected to represent background levels. The results from the samples collected downgradient of these background locations were compared and discussed.

6.5 Soil Removal Agreement

Subsequent to the collection of the residential soil samples, a soil removal action was conducted under an agreement signed in March 2008. ASARCO performed and paid for removal of contaminated soil at 15 privately owned residential parcels in Hayden and Winkelman. This cleanup work was conducted with oversight from EPA, and took place between late March and early June 2008. EPA reviewed the residential soil sample data from the RI (as presented in Section 3.1 of this report) and decided to promptly address those residential yards where the highest concentrations of arsenic, copper, and lead were found. Yards where soil contamination levels exceeded 200 mg/kg of arsenic, 2,000 mg/kg of lead, or 20,000 mg/kg of copper were selected for cleanup. Based on these soil concentration levels, the following 14 properties in Hayden were selected by EPA and then cleaned up by ASARCO:

1. 101-07-035AS
2. 101-07-040
3. 101-07-066
4. 101-07-089Q
5. 101-07-089S
6. 101-07-089T
7. 101-07-091
8. 101-09-004
9. 101-09-036
10. 101-09-039
11. 101-09-070
12. 101-09-077
13. 101-09-088
14. 101-09-140

In Winkelman, one residential yard (101-12-149) was selected by EPA and then cleaned up by ASARCO.

The soil cleanup activities consisted of removing the top one to two feet of soil, replacing it with clean fill, regrading the area, and adding a stabilizing sod cover. The interiors of some of the homes also were addressed. As a result of the soil removal activities, the soil samples collected during the RI at these parcels are no longer representative of soil conditions at these properties. Following is a discussion of the condition of the properties under baseline conditions – before the removal action. Therefore, risks/hazards at the 15 parcels where the removal action occurred are no longer present as described.

6.6 Risk and Hazard Estimates

ELCRs and non-cancer HIs were calculated as described above for residential exposure to residential soil and ambient air (plus various other exposure routes). Cancer risks for each parcel are compared to EPA's risk management range of 10^{-6} to 10^{-4} for cancer risks and the HI of 1 for non-cancer hazards (EPA, 1991b). ELCRs less than 10^{-6} or an HI less than 1 are characterized as not posing a threat to human health for the evaluated exposed populations and pathways.

6.6.1 Residential Soil

The ELCRs and HIs for soil exposure for each residential parcel evaluated are calculated based on all detected arsenic and copper concentrations found in soil samples. The potential health effects from lead are evaluated separately by calculating a lead EPC and comparing it to the site-specific, lead soil screening-level for residents. As a result, in the following sections, the potential health effects associated with lead are discussed separately from the cancer risks and non-cancer hazards for arsenic and copper.

To assess the overall potential for cancer risk and non-cancer effects from exposure to soil, incidental ingestion, inhalation of resuspended particulates, and dermal contact were evaluated. Section 6.6.3 below presents the results for exposure to ambient air, which also estimates risk and hazards from resuspended particulates as well as smelter stack emissions.

Out of the 130 residential parcels evaluated, potential risks to residents due to direct contact with soil exceeded the EPA risk management range of 10^{-6} to 10^{-4} for six parcels in Hayden and one parcel in Winkelman. Eighty-three (83) of the parcels in Hayden and Winkelman have lead concentrations that exceed the site-specific screening-level of 212 mg/kg.

6.6.1.1 Residential Soil – Hayden

This section presents the risk and hazard estimates at the 99 residential parcels sampled in Hayden. Table 6-4 presents a summary of the estimated residential cancer risks and non-cancer hazards for the residential parcels in Hayden. As shown on Table 6-5, 93 parcels in Hayden have estimated ELCRs that are within the risk management range, although all are at the upper end of the risk management range (between 10^{-5} to 10^{-4}). For non-cancer effects, 91 parcels show an HI that exceeds the threshold of 1, and only eight parcels have an HI that does not exceed that threshold. Seventy-two (72) of the parcels evaluated in Hayden have lead levels higher than the site-specific lead screening-level of 212 mg/kg.

Cancer Risks

A summary of the cancer risks, non-cancer hazards, and comparisons of lead EPCs to screening-levels for residential parcels sampled in Hayden is presented in Table 6-4. The highest ELCRs were found in Zone 9, located south of the former Kennecott Smelter area and west of the active concentrator operations. The highest arsenic concentration of 865 mg/kg was detected in a soil sample from parcel 101-07-089T in Zone 9. The arsenic EPC calculated from the nine samples collected from this parcel was 540 mg/kg. The ELCR estimated for this parcel is estimated to be 1×10^{-3} , which exceeds EPA's risk management range. The soil sample with the maximum concentration was reanalyzed and the reanalysis result, 790 mg/kg, confirmed the elevated soil arsenic level. The arsenic concentrations of the other eight sample locations collected in this parcel ranged from 32.4 to 98.5 mg/kg. This indicates that the area around the highest arsenic concentration may be a limited hot spot.

Another parcel that has high arsenic concentrations in Zone 9 is parcel 101-07-089K, located on the north side of parcel 101-07-089T. The estimated ELCR at this parcel is 2×10^{-4} (Figure 6-1).

A third parcel of concern in Zone 16 is located next to the south side of the ASARCO concentrator facility. The arsenic EPC for parcel 101-09-140 is 221 mg/kg, and the ELCR is 5×10^{-4} . Similar to parcel 101-07-089T, discussed above, the maximum concentration from

soil samples collected from this property is much higher than the other eight samples collected in the same yard. The maximum concentration of arsenic is 294 mg/kg and the range for the other eight samples is 7.1 to 94.3 mg/kg.

Parcel 101-07-034 situated in Zone 10, which is located in the northeastern section of Hayden and immediately adjacent to ASARCO's concentrator facility, has an arsenic EPC of 84.5 mg/kg and an ELCR of 2×10^{-4} . The maximum arsenic concentration of 123 mg/kg, confirmed by reanalysis (95.6 mg/kg) is higher than the arsenic concentrations in the remaining eight samples, which range from 24.8 to 33.8 mg/kg.

Parcel 101-09-038 situated in Zone 14, which is located close to concentrator operations in central Hayden, has a soil EPC for arsenic of 78.7 mg/kg and an ELCR of 2×10^{-4} . Arsenic levels in this parcel are more evenly distributed than the previous parcels discussed above. The maximum concentration of arsenic is 116 mg/kg and the other eight samples have concentrations ranging from 11.7 to 91.9 mg/kg.

Zone 2 is one of the most distant zones from active operations. The arsenic EPC from the soil data collected from Parcel 101-07-176 is 132 mg/kg and the estimated ELCR is 3×10^{-4} . There is an order-of-magnitude difference between the highest arsenic concentration (213 mg/kg) and the next highest concentration (20 mg/kg) in this parcel. The range of concentrations for the other eight samples collected is relatively low (8.4 to 20 mg/kg). Four of the eight samples had arsenic sample concentrations below the background level for arsenic of 12.5 mg/kg (Ts).

Non-Cancer Hazards

The non-cancer HIs are the sum of the HQs for arsenic and copper. In Hayden, eight parcels have HIs that do not exceed the non-cancer threshold of 1. Six of these eight parcels are located in Zones 1, 2, and 3, which are the furthest away from active operations. The remaining two parcels are located in Zone 4 and Zone 11. Table 6-5 presents the percentage of parcels that fall in each of the HI ranges discussed below. Figure 6-2 presents the HIs estimated for the Hayden parcels.

The parcels with the highest HIs (greater than 6) are located in Zones 7, 8, 9, and 10, which are south of the former Kennecott Smelter area and west of the active concentrator operations. Other parcels with HIs greater than 6 include three parcels in Zone 16 and one in Zone 14.

Exposure to Lead

As shown in Figure 6-3, elevated levels of lead are widespread in Hayden. No residential parcels in Hayden have lead EPCs lower than the background level of 47.9 (for Ts). The majority of parcels (72) evaluated had levels higher than the site-specific lead screening-level of 212 mg/kg. This site-specific level excludes the homegrown produce pathway. Nine of the 99 parcels evaluated do not exceed the site-specific lead screening-level of 122 mg/kg, which includes the homegrown produce pathway. Comparison to the Arizona R-SRL of 400 mg/kg indicates that 45 of the parcels exceed this concentration. Table 6-5 summarizes the number of parcels that fall within the different ranges of lead EPCs (using 95 percent UCLs of the surface soil lead data for the entire parcel).

6.6.1.2 Residential Soil – Winkelman

This section presents the estimated cancer risk and non-cancer health hazard for the 31 residential parcels sampled in Winkelman. As shown in Table 6-5, only one parcel (101-12-071) shows an ELCR that exceeds the risk management range. The other 30 parcels sampled in Winkelman show an ELCR that are within the risk management range. For non-cancer effects, 28 parcels have an HI below the non-cancer threshold of 1 and three parcels exceed this value. Eleven parcels evaluated in Winkelman have lead concentrations that exceed the site-specific screening-level of 212 mg/kg.

Cancer Risks

Figure 6-4 and Table 6-6 present the results of the residential cancer risks due to exposure to arsenic in soil. Table 6-5 provides the percentages of parcels that fall within three risk ranges. Only one parcel exceeds the risk management range. Two soil samples from parcel 101-12-071 had high levels of arsenic (145 mg/kg and 165 mg/kg). The other surface soil samples collected from this parcel had arsenic concentrations ranging from 4.2 to 18.4 mg/kg. The arsenic EPC used to estimate risk for this parcel is 112 mg/kg.

For the other 30 residential parcels sampled in Winkelman, the arsenic EPCs range from 4 to 45 mg/kg, and ELCRs range from 9×10^{-6} to 1×10^{-4} . Twenty-six (26) of these parcels had arsenic EPCs that were below site-specific background level (Qo) for arsenic (9.1 mg/kg).

Non-Cancer Hazards

Figure 6-5 and Table 6-6 present the results of the residential (child) hazards due to exposure to arsenic and copper in soil. Table 6-5 provides the percentages of parcels that fall within different HI ranges. Of the three parcels that exceed the non-cancer threshold, two of the parcels show an HI of 3 and one (parcel 101-12-071) shows an HI of 4. The elevated HI at parcel 101-12-071 is due to the high arsenic concentrations in the soil samples (95 percent of the HI is from arsenic and five percent is from copper). The parcels with the HI of 3 are located adjacent to each other in Zone 21. They are parcels 101-12-149 and 101-12-150. The contribution to the HI for both parcels is approximately 50 percent from arsenic and 50 percent from copper.

Exposure to Lead

Figure 6-6 presents the lead EPCs for Winkelman, color-coded corresponding to the following ranges of soil concentrations:

- Blue - less than 122 mg/kg (site-specific lead screening-level including homegrown produce pathway)
- Yellow - between 122 mg/kg and 212 mg/kg (site-specific lead screening-level excluding homegrown produce pathway)
- Red - greater than 212 mg/kg

Table 6-5 provides the percentages of the parcels that fall within each of these ranges. Three parcels are below the background lead level for Qo of 45.8 mg/kg.

6.6.2 Non-Residential Soil

The non-residential exposure areas include six areas in Hayden, four areas in Winkelman, 14 areas associated with the ASARCO Properties, and 11 areas in Outlying Areas. Cancer risks and non-cancer hazards for all these areas due to arsenic and copper are shown in Figures 6-7 through 6-12; and comparisons of the lead EPCs with site-specific screening-levels are shown in Figures 6-13 through 6-15. Summaries of the cancer risks and non-cancer hazards for each area are presented in Tables 6-7 through 6-10.

6.6.2.1 Hayden

The exposure areas associated with the town of Hayden include the Hayden Public Areas, the Hayden Golf Course (divided into two subareas), and the San Pedro Wash, Kennecott Avenue Wash, and Power House Wash. The receptors evaluated for these areas include a child playing at the park, an adult golfer, and a child and adult trespasser (using in-town exposure assumptions). Table 6-7 provides the arsenic, copper, and lead EPCs for the Hayden exposure areas, as well as the estimated cancer risks and non-cancer HIs. Five of these areas have estimated cancer risks that are within and one exposure area has estimated risk below the EPA risk management range. However, the non-cancer HIs exceed 1 for Power House Wash (HI = 2) and the Hayden Community Park/Library area (HI = 4). For both of these areas, the main contributor to the HI is copper.

As shown in Figures 6-13 and 6-15, each of these six exposure areas has a lead EPC less than the site-specific risk-based screening-level of 212 mg/kg (excludes homegrown produce pathway). However, two of these areas, including the Northwest Hayden Golf Club and Power House Wash, have lead EPCs that exceed the site-specific risk-based screening-level of 122 mg/kg, which takes homegrown produce into account.

6.6.2.2 Winkelman

The exposure areas associated with the town of Winkelman include the WSC and three residential properties associated with the school. As noted in Section 3.1.4.2, these three properties/trailers are on school property; however, as a conservative estimate of risk, the residential exposure scenario was used. The receptors include a school child and residential adult and child. Table 6-8 provides the arsenic, copper, and lead EPCs for the Winkelman exposure areas, as well as the estimated cancer risks and non-cancer HIs. As shown in Figures 6-9 and 6-10, these four exposure areas have estimated cancer risks that are within the EPA risk management range, and non-cancer HIs that do not exceed the non-cancer threshold of 1. As shown in Figure 6-14, each of these four areas has a lead EPC that is less than both site-specific risk-based screening-levels of 212 mg/kg and 122 mg/kg.

6.6.2.3 ASARCO Properties

The ASARCO Properties include the five subareas located around the Kennecott Smelter evaluated for a remote trespasser, and the nine subareas located on the west side of the town of Hayden, which were evaluated for an in-town trespasser. Table 6-9 provides the arsenic, copper, and lead EPCs for the ASARCO Properties exposure areas, as well as the estimated cancer risks and non-cancer HIs. The estimated cancer risks at all of the exposure areas in the ASARCO Properties grouping are within the EPA risk management range, with the exception of the East of Hillcrest Avenue area, which exceeds 1×10^{-4} . However, the non-cancer HIs at

all 14 of these exposure areas, except 5th Street Right-of-Way and Crusher Facility, exceed the non-cancer threshold of 1. The HIs range from 2 (at the South of Mill Building exposure area) to 28 (at the East of Hillcrest Avenue exposure area). As shown in Figure 6-13, seven of the 14 exposure areas have lead EPCs that exceed the site-specific risk-based screening-levels of both 212 mg/kg and 122 mg/kg for lead. These areas include the Kennecott Smelter – North End, Basin, Lime Plant, and South of Lime Plant; West of Administration Building; East of Hillcrest Avenue; and North of Mill Building exposure areas.

6.6.2.4 Outlying Areas

As shown in Figures 6-11 and 6-12, 11 exposure areas were categorized in the Outlying Areas grouping. The remote trespasser bike-riding youth and occasional hiking adult were evaluated for these areas. Table 6-10 provides the arsenic, copper, and lead EPCs for the Outlying Areas exposure area, as well as the estimated cancer risks and non-cancer HIs. As shown in Figure 6-11, all of the exposure areas in the Outlying Areas grouping have estimated cancer risks that are within the EPA risk management range, although one of the areas (Slag Dump) is at the upper end of the range with an estimated cancer risk of 9×10^{-5} . As shown in Figure 6-12, the non-cancer HIs do not exceed the non-cancer threshold of 1 except at the Slag Dump area where the HI is 31. The arsenic EPC is 249 mg/kg and the copper EPC is 380,000 mg/kg at this exposure area. As shown in Figure 6-15, three of the 11 exposure areas have lead EPCs that exceed the site-specific risk-based screening-levels of 212 mg/kg and 122 mg/kg for lead. These areas include the Tertiary Sediments – South of Smelter, Slag Dump, and State Route 77 exposure areas.

6.6.3 Air

As noted in Section 6.5.1, the potential risks and hazards associated with exposure to ambient air include both resuspension of particulates and ongoing smelter stack emissions. Estimated cancer risks are presented for arsenic, cadmium, and chromium detected in ambient air at the two air monitoring stations established as part of the RI. One air monitoring station is located in Hayden and one station is located in Winkelman. The locations of the two air monitoring stations in Hayden and Winkelman are shown in Figure 3-4.

Non-cancer inhalation RfDs were not available for the air COCs evaluated. Therefore, non-cancer hazards were not considered in this ambient air assessment. For copper and lead, a qualitative approach was conducted. Comparisons of concentrations found in Hayden and Winkelman air to background air concentrations are presented in Table 6-3. The concentrations of metals in air are significantly higher in Hayden when compared to Winkelman. Air samples from both the Hayden and Winkelman monitoring stations have levels of metals in air that are significantly higher than background levels found at the IMPROVE Organ Pipe Station.

Comparisons of concentrations of these metals from the Site to Cal-EPA's acute recommended exposure limits (RELs) and comparison of lead concentrations to NAAQS are presented for Hayden and Winkelman in the following sections.

6.6.3.1 Exposure to Air – Hayden

Appendix C presents the potential cancer risk for residential exposures to ambient air in Hayden. The ELCR calculated from the EPCs for arsenic, cadmium, and chromium is 1×10^{-4} , which is at the upper end of the EPA risk management range. Of the total cancer risk, 80 percent of the risk contribution is from arsenic, 9 percent is from cadmium, and 11 percent is from chromium. As discussed in Section 4.0 of Volume I of the RI Report (CH2M HILL, 2008), several dates during the sampling period had elevated levels of arsenic.

- **Arsenic:** The highest concentration of arsenic detected over a 24-hour sampling period was $0.19 \mu\text{g}/\text{m}^3$. This arsenic concentration over a 24-hour sampling period equals the REL of $0.19 \mu\text{g}/\text{m}^3$, which is for a four-hour averaging time.
- **Lead:** The Hayden EPC (95 percent UCL) for lead of $0.183 \mu\text{g}/\text{m}^3$ is much less than the EPA NAAQS of $1.5 \mu\text{g}/\text{m}^3$ (quarterly average) and within the range of EPA's proposed revision to the lead NAAQS, which is 0.1 to $0.3 \mu\text{g}/\text{m}^3$ (EPA, 2008d).

6.6.3.2 Exposure to Air – Winkelman

Appendix C presents the potential cancer risk for exposures of a resident to ambient air in Winkelman.

- **Arsenic, Cadmium, and Chromium:** The ELCR calculated from the EPCs for arsenic, cadmium, and chromium from the Winkelman air monitoring station is 4×10^{-5} , which are within the EPA risk management range. Of the total risk, 64 percent is from arsenic, 6 percent is from cadmium, and 30 percent is from chromium.
- **Lead:** The Winkelman 95 percent UCL lead concentration of $0.0281 \mu\text{g}/\text{m}^3$ is much less than the EPA NAAQS of $1.5 \mu\text{g}/\text{m}^3$ (quarterly average) and below the range of EPA's proposed revision to the lead NAAQS, which is 0.1 to $0.3 \mu\text{g}/\text{m}^3$ (EPA 2008d).

6.6.4 Groundwater

Screening-level cancer risks and health hazards associated with residential exposure to groundwater at Hayden and Winkelman were estimated. For the purposes of this screening-level evaluation, the potential for unacceptable cancer risk or human health hazard was identified using the following criteria:

ELCRs are compared against the EPA risk management range of 10^{-6} to 10^{-4} for cancer risks and the HI benchmark of 1 for non-cancer hazards (EPA, 1991b). Exposure groupings with ELCRs less than 10^{-6} or an HI less than 1 are characterized as not posing a threat to human health for the evaluated exposed populations and pathways.

6.6.4.1 Chemical Evaluation

As presented in Table 6-11, the results of the screening-level groundwater evaluation shows ELCRs ranging from 9×10^{-5} to 4×10^{-4} for all groundwater data groupings. Non-cancer HIs range from 1 to 35. Appendix D contains the risk calculation tables and provides the EPC for each COC, the screening-levels (EPA tap water PRG), the risk and hazard ratios, and the cumulative risks and HIs. The tables also present the percent contributions for each chemical.

Following is a detailed discussion of the risk results:

Drinking Water Aquifer: For residential exposure to drinking water from the aquifers, the cancer risk is 2×10^{-4} . Arsenic contributes 100 percent of the cumulative cancer risk. The non-cancer HI is 7; manganese contributes more than 60 percent of the HI and is the only chemical that has an HQ that exceeds 1.

Non-Drinking Water Aquifer: For exposure to groundwater from the non-drinking water aquifer, the cancer risk is 4×10^{-3} . The primary risk driver is arsenic (99 percent of the cumulative cancer risk). The non-cancer HI is 35, and arsenic contributes almost 50 percent of the HI. Molybdenum contributes almost 10 percent of the HI. Arsenic, molybdenum, selenium, and vanadium have HQs that exceed 1.

Hayden Municipal Supply Well and Manifold Samples: For exposure to groundwater from the Hayden municipal supply well and manifolds, the cancer risk is estimated at 9×10^{-5} , with arsenic contributing 100 percent of the total risk. The non-cancer HI is 2, with uranium contributing more than 50 percent of the HI, followed by arsenic (18 percent) and vanadium (11 percent). No individual chemical has an HQ that exceeds 1.

Winkelman Municipal Supply Well and Manifold Samples: For exposure to groundwater from the Winkelman municipal supply well and manifolds, the cancer risk is 1×10^{-4} , with arsenic contributing to over 70 percent of the total risk in addition to chlorodibromomethane (13 percent) and bromodichloromethane (10 percent). The non-cancer HI is 2, with uranium contributing to over 30 percent of the total HI, followed by arsenic (26 percent) and manganese (13 percent). No individual chemical has an HQ that exceeds 1.

Tap Water: For exposure to tap water from the Hayden Library, the cancer risk is 1×10^{-4} , with arsenic as the only risk driver (100 percent). The non-cancer HI is 2, with uranium contributing 41 percent of the total HI in addition to arsenic (28 percent), vanadium (16 percent), and molybdenum (13 percent). No individual chemical has an HQ that exceeds 1.

For exposure to the drinking fountain water from Winkelman Elementary School, the cancer risk is 1×10^{-4} , with arsenic as the only risk driver (100 percent). The HI does not exceed the non-cancer threshold of 1, with uranium contributing 36 percent of the cumulative HI as well as arsenic (32 percent) and vanadium (17 percent). No individual chemical has an HQ that exceeds 1.

Lead EPCs for all the data groupings were below the MCL of 15 $\mu\text{g}/\text{L}$.

The primary contributor to risk for each of the data groupings is arsenic. Because there is no Site-specific background groundwater quality study, arsenic EPCs were compared to local groundwater background levels from monitoring wells in unaffected areas of Maricopa County, which is adjacent and just west of Gila County. According to the USGS National Water Quality Assessment (NAWQA) Data Warehouse, arsenic groundwater concentrations range from 1 to 81 $\mu\text{g}/\text{L}$ (USGS, 2008). The county groundwater data were collected between 1997 and 2007. The average arsenic groundwater concentration in Maricopa County is 13 $\mu\text{g}/\text{L}$. The arsenic EPCs for the four exposure area groupings evaluated range from 4 to 7.4 $\mu\text{g}/\text{L}$ which are generally below the NAWQA background levels. The only arsenic EPC that is substantially higher than the background levels is from the non-drinking

water aquifer data grouping (175 µg/L). The range of arsenic EPCs in the other groupings is 3.98 µg/L from the Hayden Municipal Supply Wells to 7.41 µg/L from the Drinking Water Aquifer Supply Wells.

6.6.4.2 Radionuclides Evaluation

As presented in Table 6-12, the results of the radionuclides screening-level calculations exceeded the EPA risk management range with estimated risks ranging from 4×10^{-6} to 6×10^{-4} for all four groundwater data groupings. Appendix D contains the risk-calculation tables that show the EPCs, the screening-levels, the risk and hazard ratios, and the cumulative risks and HIs. The tables also present the percent contributions for each chemical.

Following is a detailed discussion of the risks and hazards:

Drinking Water Aquifer: For residential exposure to drinking water from the aquifers, the cancer risks are 5×10^{-4} . Radium 226 contributes 97 percent of the cumulative cancer risk.

Non-Drinking Water Aquifer: For residential exposure to non-drinking water from the aquifer monitoring wells, the cancer risk is 4×10^{-4} . The primary risk driver is radium 226 (97 percent of the cumulative cancer risk).

Hayden Municipal Supply Well and Manifold Samples: For residential exposure to groundwater from the Hayden municipal supply well and manifolds, the cancer risk estimate is 6×10^{-4} , with radium 226 contributing 98 percent of the total risk.

Winkelman Municipal Supply Well and Manifold Samples: For residential exposure to groundwater from the Winkelman municipal supply well and manifolds, the cancer risk is 5×10^{-6} with uranium 234 contributing 76 percent of the total risk.

Tap Water: For residential exposure to tap water from the Hayden Library drinking fountain, the cancer risk is 4×10^{-6} with uranium 234 contributing to 65 percent of the total risk. For residential exposure to tap water from Winkelman Elementary School drinking fountain, the cancer risk is 4×10^{-6} with uranium 234 contributing to 74 percent of the total risk.

The primary risk driver for the drinking water aquifer, non-drinking water aquifer, and Hayden municipal supply well and manifold samples data groupings is Radium 226. The cumulative risks for these data groupings range from 4×10^{-4} to 6×10^{-4} . EPA regulates radium 226 in drinking water and promulgated an MCL of 5 picocuries per liter (pCi/L) in 1975 (EPA, 2008c). All of the radium 226 EPCs are well below the MCL of 5 pCi/L (Site EPCs range from 0.3 to 0.5 pCi/L). Because there is no Site-specific background groundwater quality study for radionuclides, the EPCs for Radium 226 were compared to the national median concentration of 0.39 pCi/L (USGS, 1998). The range of Radium 226 radioactivity in the four groundwater groupings is 0.3 to 0.8 pCi/L (both the minimum and maximum concentrations are from the drinking water aquifer data grouping). The national maximum concentration was approximately 15 pCi/L. The radium 226 EPCs are within the range of national background concentrations.

The cumulative risk results for the Winkelman municipal supply well and manifold samples and the tap water data groupings are within EPA's risk management range of 10^{-6} to 10^{-4} .

6.6.5 Surface Water

Potential cancer risks and non-cancer hazards for recreational exposure of adult and child receptors to surface water in the Gila River and San Pedro River are presented in Appendix E. A summary of adult and child cancer risks and child non-cancer hazards is presented in Table 6-13. The cancer risk for exposure to surface water by a recreational swimmer is 2×10^{-6} , which is at the lower end of the EPA risk management range. The child non-cancer HI calculated from the EPCs for aluminum, arsenic, iron, manganese, and vanadium is less than the non-cancer threshold of 1. Aluminum, arsenic, iron, manganese and lead EPCs exceeded background concentrations. Arsenic exceeded PRGs in background samples as well as in vicinity/downstream surface water samples. However, arsenic concentrations in the surface water samples (maximum concentration of 16.8 $\mu\text{g/L}$) were higher in comparison to background concentrations (maximum concentration of 7.7 $\mu\text{g/L}$). The lead EPC and lead background level also exceeded the MCL.

6.6.6 Sediment

Potential cancer risks and non-cancer hazards for recreational exposure of a recreational angler to in-stream sediment in the Gila River and San Pedro River are presented in Appendix F, Table F-1 through F-4. For lead, a comparison of lead concentrations in sediment with site-specific screening-levels is presented in Appendix F, Table F-5. A summary of cancer risks and non-cancer hazards is presented in Table 6-14. The cancer risk for sediments is 2×10^{-6} , which is at the low end of EPA's risk management range. The exposure route which contributes the most to total risk is the oral route, which contributed 89 percent to the total risk. The non-cancer HI calculated from the EPCs for arsenic, copper, iron, manganese, and vanadium is less than the non-cancer threshold of 1.

The lead concentrations in sediment are below the lead screening-levels of 122 mg/kg and 212 mg/kg. The lead EPC also exceeded the background level.

6.6.7 Indoor/Attic Dust

This section provides the results of the dust sample evaluation for metals from the residential indoor and attic dust investigation in Hayden and Winkelman. The objectives of the qualitative analysis are:

- To compare concentrations of metals in indoor and attic dust to Arizona R-SRLs
- To identify metals of the greatest concern in indoor dust and attic dust

A qualitative screening-level approach was selected because dust samples were collected from only 22 homes, which included 18 homes in Hayden and four homes in Winkelman. Dust concentrations were compared to Arizona R-SRLs. The dust samples were collected by judgmental directed sampling where dust would tend to accumulate (along floorboards and window sills in the occupied areas, and in attics near the access doors where present) rather than by random sampling. From the 22 homes sampled, 33 investigative samples were collected, which consisted of 22 indoor dust samples (one from each home) and 11 attic dust samples.

6.6.7.1 Hayden Indoor and Attic Dust Results

The Hayden dust sampling effort included the collection of indoor dust samples from occupied areas in 18 homes, and collection of attic dust samples from nine of the 18 homes.

In Hayden, 16 of 18 indoor dust samples exceeded the arsenic Arizona R-SRL of 10 mg/kg; 14 of 18 indoor dust samples exceeded the copper Arizona R-SRL of 3,100 mg/kg; and eight of 18 samples exceeded the lead Arizona R-SRL of 400 mg/kg. All nine attic dust samples collected in Hayden exceeded the Arizona R-SRLs for arsenic, copper, and lead.

The highest detected arsenic and copper concentrations of 259 mg/kg and 34,600 mg/kg, respectively, were detected in the same attic dust sample (Parcel 101-07-061 in Zone 9). The highest lead concentration of 88,600 mg/kg was detected in an indoor dust sample (Parcel 101-07-046 in Zone 10). Generally, higher concentrations of metals were found in the attic dust samples relative to indoor dust samples. Additionally, higher indoor and attic dust metal concentrations were found in residences located closer to active concentrator operations.

6.6.7.2 Comparison of Dust and Soil Sample Results – Hayden

Tables 6-15, 6-16, and 6-17 provide comparisons of the attic and indoor dust results with the results of surface soil (from the yards of the homes) for arsenic, copper, and lead. The surface soil samples were collected from a depth of 0 to 2 inches bgl. In addition to presenting the 95 percent UCL concentration (determined using the nine surface soil results collected in each yard), the metals concentration results from the surface soil sample collected closest to the main and side/back entrance are provided. Appendix G (Figures G-1 through G-4) provide comparisons of the attic and indoor dust sample results with the outdoor surface soil results. Figure G-1 presents arsenic concentrations. Figure G-2 presents copper concentrations. Figures G-3 and G-4 present lead concentrations. Figure G-1 excludes Parcel 101-07-089T because the elevated arsenic concentration in surface soil would make the scale on the figure too large to see the differences in concentrations at the other parcels. For lead, dust sample results for three of the parcels are presented in Figure G-4, due to elevated lead concentrations detected in the three parcels.

The following observations can be made from the tables and figures that compare the dust and soil sample results:

- The attic dust results for arsenic and copper are generally higher for most homes than the indoor dust and soil results. Additionally, all nine attic dust samples collected in Hayden exceed the Arizona R-SRL screening-levels.
- For copper, four of the attic dust samples were greater than (generally, by a factor of 2) the indoor dust samples collected from the same home. One indoor copper dust result was higher than the corresponding attic dust result (Parcel 101-09-077).
- Concentrations of arsenic in indoor dust and outdoor soil are similar for many of the parcels. However, for some parcels, the arsenic concentrations in the two media are significantly different, including Parcel 101-07-089T where the indoor dust arsenic is 49.7 mg/kg and surface soil arsenic is 540 mg/kg (Table 4-3) and Parcel 101-07-111 where the indoor dust arsenic is 209 mg/kg and surface soil arsenic is 15.3 mg/kg.

- For copper, 10 homes have higher surface soil results than indoor dust results. Seven homes have higher indoor dust results than surface soil results.
- Concentrations of lead are high for indoor dust and for outdoor soil at Parcels 101-07-070, 101-09-077 and 101-09-106. The indoor dust sample collected from Parcel 101-07-046 is very high (88,600 mg/kg), while the outdoor surface soil sample result is 734 mg/kg.

6.6.7.3 Winkelman Indoor and Attic Dust Results

The Winkelman dust sampling effort included the collection of dust samples from indoor occupied areas at four homes, and collection of attic dust samples from two of the four homes.

In Winkelman, only one of the four indoor dust samples (Parcel 101-12-093 at 10.2 mg/kg) slightly exceeded the arsenic Arizona R-SRL, and no indoor dust samples exceeded the copper or lead Arizona R-SRLs. Both attic dust samples collected in Winkelman exceeded the Arizona R-SRL for arsenic (with a maximum concentration of 54 mg/kg at Parcel 101-12-241), but neither exceeded the copper and lead Arizona R-SRLs.

Additionally, the indoor dust sample at Parcel 101-12-093 had antimony concentrations of 110 mg/kg, which is above the Arizona R-SRL of 31 mg/kg. In the attic dust sample at Parcel 101-12-241, the antimony concentration of 112 mg/kg was also above the Arizona R-SRL.

6.6.7.4 Comparison of Dust and Soil Sample Results - Winkelman

Tables 6-15, 6-16 and 6-17 provide a comparison of attic and indoor dust sample results with the results of surface soil samples (0 to 2 inches bgl) collected in the yards of the homes where the dust samples were collected for arsenic, copper, and lead. In addition to presenting the 95 percent UCL (which was determined by using all nine surface soil sample results collected in each yard), the metals concentration results are provided for the surface soil sample collected closest to the main and side/back entrance. Appendix G (Figures G-5, G-6, and G-7) provide a comparison of the attic and indoor dust sample results with the outdoor surface soil results. The following observations can be made from the dust results comparison tables and figures:

- All of the Winkelman indoor dust samples (collected from four homes) except parcel 101-12-093 (arsenic concentration of 10.2 mg/kg) have arsenic results that are below the Winkelman site-specific soil background level (Qo) for arsenic of 9.1 mg/kg, while the arsenic results for surface soil are similarly low (below site-specific soil background levels).
- The attic dust sample results show higher concentrations of arsenic than the corresponding indoor dust sample results.
- All attic and indoor dust sample results for copper and lead are below the Arizona R-SRLs.

6.6.7.5 Comparison of Hayden and Winkelman Indoor and Attic Dust Results

The concentrations of arsenic, copper, and lead in the indoor and attic dust samples are markedly higher in the Hayden residences compared with the Winkelman residences.

Nearly all indoor and attic dust samples collected in Hayden had concentrations of arsenic, copper, and lead above the Arizona R-SRLs. Concentrations generally decline in homes located further from the concentrator operations, and results from Parcel 101-07-049 in Zone 4 showed the lowest concentrations of any indoor samples in Hayden. The homes adjacent to Conveyor 9 and near the concentrator are more exposed to fugitive dust emissions from the material-handling activities and to the process-generated emissions from the smelter facility. Those homes tend to have higher dust concentrations of arsenic, copper, and lead.

6.6.8 Multi-Pathway Cumulative Risks

As a means of evaluating multi-pathway cumulative risks and comparing the relative contribution to risk from multi-pathway exposures, the sum of the residential soil and ambient air cancer risks was calculated for three different soil and ambient air exposure combinations for both Hayden and Winkelman. The following examples are representative of the range of combined soil and ambient air cancer risks for residents in Hayden and Winkelman (Tables 6-18 and 6-19):

- Example 1 (Background). The sum of soil background risk plus air monitoring background risks.
- Example 2 (Mid-Levels Soils Concentrations). In Hayden, the sum of soil risks associated with soil arsenic at 26 mg/kg (5×10^{-5} cancer risk) plus the corresponding risks associated with air monitoring data from Hayden. For Winkelman, the sum of soil risks associated with soil arsenic at 20 mg/kg (4×10^{-5} cancer risk) plus the corresponding risks associated with air monitoring data from Winkelman.
- Example 3 (High-Levels Soils Concentrations). The sum of soil risks for the highest concentration property (assumed highest level of soil arsenic after forthcoming remediation of properties): 132 mg/kg arsenic in Hayden, 112 mg/kg arsenic in Winkelman) plus air monitoring risks.

6.6.8.1 Risks from Soil plus Air – Hayden

For Hayden the sum of residential soil plus ambient air cancer risk was calculated for:

- Soil background plus air monitoring background: 3×10^{-5} cancer risk
- 26 mg/kg arsenic in soil plus ambient air: 2×10^{-4} cancer risk
- 132 mg/kg arsenic in soil (maximum remaining concentration after initial cleanup) plus ambient air: 4×10^{-4} cancer risk

Cancer risks in Hayden were greater than the background cancer risks. Ambient air cancer risks were 1×10^{-4} ; all additional incremental risks are assumed to be due to residential soil exposure in Hayden.

6.6.8.2 Risks from Soil plus Air – Winkelman

For Winkelman the sum of residential soil plus ambient air cancer risk was calculated for:

- Soil background plus air monitoring background: 3×10^{-5} cancer risk
- 20 mg/kg arsenic in soil plus ambient air: 8×10^{-5} cancer risk

- 112 mg/kg arsenic in soil (maximum remaining concentration after initial cleanup) plus ambient air: 2×10^{-4} cancer risk

Cancer risks in Winkelman were greater than the background cancer risks. Ambient air cancer risks were 4×10^{-5} ; all additional incremental risks are assumed to be due to residential soil exposure in Winkelman.

7. Uncertainty Evaluation

An uncertainty evaluation describes uncertainties associated with a risk assessment, including data gaps in the toxicological and exposure assessment information, and conservative assumptions or scientific judgments used to bridge these data gaps (EPA, 1992). The uncertainties, which arise at every step in the risk assessment process, are evaluated to provide an indication of the relative degree of conservatism associated with a risk estimate. This section presents a qualitative discussion of the uncertainties associated with the overall assessment process.

Risk assessments are not intended to predict actual health effects to a receptor associated with exposure to chemicals in the environment. Rather, risk assessment is a means of estimating the upper-bound probability that an adverse health effect (e.g., cancer) may occur in a receptor at some point in the future under an assumed set of exposure conditions. The multitude of conservative assumptions used in the process ensures that the risk estimates are not likely to be under-estimated.

Risk estimates are calculated by combining data, assumptions about individual receptor's exposure to impacted media, and toxicity data. Uncertainties within this risk assessment can be grouped into the following categories:

- Environmental sampling and analysis
- Assumptions concerning exposure scenarios
- Toxicity data and dose response extrapolations
- Cancer risk and non-cancer hazard characterization
- Qualitative Evaluation of Indoor and Attic Dust

7.1 Environmental Sampling and Analysis

This risk assessment is based on the sampling results obtained during the RI at the Site. Errors in sampling results can arise during the field sampling, laboratory analyses, and data analyses. Uncertainties associated with sampling and analyses include the inherent variability (standard error) in the analysis, representativeness of the samples, sampling errors, and heterogeneity of the sample matrix. Heterogeneity of the sample matrix is especially of concern for soil samples. The relative percent difference between results for normal and field duplicate samples are used to evaluate this heterogeneity.

While the quality assurance/quality control (QA/QC) program used in conducting the sampling and analysis serves to reduce errors, it cannot eliminate all errors associated with sampling and analysis. Errors in laboratory analysis procedures are possible, although the impacts of these sorts of errors on the risk estimates are likely to be low, because of the thorough data validation process that is part of the RI procedures for EPA Region 9 sites.

The environmental sampling at a site is one source of uncertainty in the evaluation. The analytical analyses (i.e., metals) are considered representative of potential releases based on the operational history of the site. The number and location of residential surface soil samples and ambient air samples collected in Hayden and Winkelman are considered adequate for the risk assessment. Up to nine surface soil samples per residential parcel were collected and analyzed for metals. This number of samples is considered adequate to calculate EPCs that are representative of average exposure for residents at their properties.

For the non-residential soil areas (some exposure areas have only one soil sample), groundwater (two sampling events), surface water, and sediment sampling (two sampling events), the data sets are limited so there is some uncertainty associated with the risk/hazard estimates for these media. However, in cases with small data sets, the EPC is the maximum detected concentration.

Some uncertainties are associated with the representativeness of the background data set. Uncertainty is associated with the small background data sets for the "Qo" soil type (used to compare to Winkelman soil data) consisting of only six samples, and the surface water and sediment background data sets consist of only two samples each. The background air samples were compiled from an air monitoring station in the Sonoran Desert (IMPROVE Organ Pipe National Park) to attempt to match the climate and conditions of the Site, however, since these background samples were not collected specifically for this Site, there is uncertainty associated with this data set as well.

7.2 Exposure Assessment

The exposure assessment of the HHRA includes a determination of EPCs, selection of exposure assumptions, and modeling of chemical intakes. The estimation of exposure requires numerous assumptions to describe potential exposure routes. There are a number of uncertainties regarding the likelihood of exposure, frequency of contact with contaminated media, the concentration of contaminants at exposure points, and the time period of exposure. Assumptions used tend to simplify and conservatively approximate actual site conditions, thereby serving to maximize confidence in decision making during the HHRA.

7.2.1 Exposure Point Concentrations

Residential soil samples were collected from the Site investigation areas both near suspected source areas and also in portions of Hayden and Winkelman that were expected to be increasingly distant from source areas. Therefore, the residential soil data sets are assumed to be representative of most settings in Hayden and Winkelman. For this reason, the EPCs for the 17 zones in Hayden and 11 zones in Winkelman are thought to be representative of contaminated soil conditions in Hayden and Winkelman.

For the soil assessment, a county tax assessor parcel, which defines a residential property boundary, was used as an exposure area. Uncertainty in the EPCs for the exposure areas may be attributable to several factors:

- All surface soils were collected from 0 to 2 inches bgl. This sampling range is considered to be representative of the surface soil depths to which residents of Hayden and

Winkelman would be routinely exposed. If other activities result in residents being exposed to soil at deeper intervals, risks and hazards may be over- or under-estimated depending on the depth profile of concentrations of metals in soil.

- The EPCs use data from all areas of the residential properties regardless if there is pavement or vegetation covering the soil. Because the residential properties in Hayden are largely bare and unvegetated, this assumption should not result in significant over-estimations of actual risk. However, for residential properties with large areas of pavement and/or dense vegetation or grass, the EPCs may result in an over-estimation of current risks and hazards since all areas of the properties are not accessible to residents.
- Use of the 95 percent UCL as the EPCs is based on the assumption that exposure occurs across all parts of the property sampled. This could result in an over-estimation or under-estimation of risk and hazard if children, or others at the residence, actually play or engage in activities where they are exposed to soil in a smaller area of the property.
- Some of the non-residential locations had limited data available, which were not adequate for calculating a 95 percent UCL. In these cases, the maximum reported concentration was used as an EPC. For some of these exposure areas, the EPC is based on a single sample result. This approach for EPC determination may over-estimate the actual EPC. However, it is also possible that a larger sample size would result in the identification of greater chemical concentrations, which could increase the estimated EPC.

7.2.2 Exposure Assumptions

The estimation of exposure requires many assumptions to describe potential exposure situations. There are uncertainties regarding the likelihood of exposure, frequency of contact with contaminated media, the concentration of contaminants at exposure points, and the period of exposure. These tend to simplify and approximate actual site conditions. In general, these assumptions are upper-bound assumptions intended to be conservative and yield an over-estimate of the site-related cancer risk or non-cancer hazard.

Exposure assumptions derived from established guidance documents are typically based on one or more scientific studies with a statistically defensible sample size. For this HHRA, several site-specific exposure factors are used for the trespasser and recreational scenarios instead of more standard default exposure factors. Although this approach is intended to reflect conditions unique to the Site, these site-specific values have uncertainty associated with them because they are not based on a statistically significant number of observations.

7.2.3 Potentially Complete Exposure Pathways

As noted in Section 2.2, ingestion of garden vegetables and ingestion of fish from the Gila River and San Pedro River are potentially complete pathways, but were not evaluated quantitatively in this HHRA.

The vegetable ingestion pathway was included in the calculation of the risk-based screening-level for lead based on the assumption that seven percent of the diet is from homegrown sources. However, for other metals, the vegetable ingestion pathway was not quantitatively evaluated. In general, there are no gardens in the Hayden or Winkelman

residential properties so this pathway is not expected to be significant for the residents. However, there is uncertainty related to the cumulative risk estimates for all exposure pathways if residents in the future would plant gardens and consume homegrown vegetables.

Although potentially complete, the fish ingestion pathway is also not expected to be significant for residents. As described in Section 3.4, several metals were measured in surface water in the Gila and San Pedro Rivers at levels greater than in the background locations and greater than EPA tap water PRGs. The main COC for surface water is arsenic. Fish can accumulate arsenic; however, most of this arsenic in fish is in an organic form called arsenobetaine that is much less harmful than inorganic forms (ATSDR, 2007b). Although the fish consumption pathway is not expected to be a large contributor to potential risks for residents, there is uncertainty related to the cumulative risk estimates for all exposure pathways for residents if fish caught from the Gila and San Pedro Rivers are a significant part of the residents' diet.

7.2.4 Screening-Level Groundwater Evaluation

A screening-level groundwater evaluation was developed, and risks and hazards were estimated by a comparison of groundwater concentrations to EPA's risk-based tap water PRGs and radionuclide PRGs from EPA's ORNL website. Both EPA and Cal-EPA recommend the use of these screening-levels in screening-level health risk estimates. However, simplifying assumptions are used for the screening-levels, and the baseline HHRA is more comprehensive and site-specific. For example, the EPA tap water PRGs for chemicals include the ingestion and inhalation exposure routes, but not the dermal exposure route. However, since ingestion is typically the major exposure route for groundwater, the screening-level approach for groundwater used in this HHRA is considered adequate.

A few metals were not evaluated quantitatively for cancer risk because risk-based tap water concentrations were not available in the EPA Region 9 PRG table. This might result in an under-estimation of cumulative risk for the individual data groupings.

7.3 Toxicological Data

The availability and quality of toxicological data is another source of uncertainty in the risk assessment. EPA has outlined some of the sources of uncertainty in the *Risk Assessment Guidance for Superfund* (EPA, 1989). These sources may include or result from the extrapolation from high to low doses and from animals to humans; the species, gender, age, and strain differences in the uptake of a toxin; metabolism, organ distribution, and target site susceptibility; and the human population's variability with respect to diet, environment, activity patterns, and cultural factors.

In establishment of the non-carcinogenic criteria, conservative multipliers, known as uncertainty and modifying factors, are used. EPA has not published dermal RfDs or slope factors; therefore, oral toxicity factors were used to estimate absorbed dose. This may result in an under- or over-estimate of risks, depending on whether a chemical is more or less toxic by the dermal route versus ingestion.

The EPA oral CSF for arsenic (1.5 mg/kg-day⁻¹) is used to estimate potential cancer risk for ingestion of residential soil. The Cal-EPA Office of Environmental Health Hazard Assessment (OEHHA) oral CSF for arsenic (9.5 mg/kg-day⁻¹) is more than six times greater than the EPA CSF. Use of the EPA CSF compared to the OEHHA CSF is a source of potential uncertainty depending on which oral CSF is a more-representative value for estimating cancer risk for soil ingestion at this Site. If the OEHHA CSF is more representative, the risks presented are under-estimated.

7.4 Risk Characterization

This risk assessment presents numerical estimates of risks; however, it is important to note that these numbers do not predict actual health outcomes. Because of the conservative assumptions used for the risk assessment, these estimates are calculated in a way that tends to over-estimate risks, and thus any actual risks are likely to be lower than these estimates. This section presents a discussion of some of the key uncertainties in the risk characterization step of this HHRA.

7.4.1 Cumulative Risks and Hazard Indices

In the risk characterization, the assumption is made that the total risk of developing cancer from exposure to site contaminants is the sum of the risk attributed to each individual contaminant. Likewise, the potential for the development of non-cancer adverse effects is the sum of the HQs estimated for exposure to each individual contaminant. This approach is consistent with EPA guidance; however, the approach does not account for the possibility that constituents act synergistically or antagonistically. Therefore, there is uncertainty associated with the cumulative risks for carcinogens and HIs for non-carcinogens.

The evaluation of non-cancer hazards for the residential parcels included two metals, arsenic and copper. The HIs presented in the Risk Characterization section are the sum of the individual HQs for these metals. The critical effects for oral exposure to arsenic are hyperpigmentation, keratosis, and possible vascular complications (EPA, 2008a). The critical effect for oral exposure to copper is gastrointestinal system irritation (EPA, 1997). For two parcels in Hayden, the sum of the HQs for arsenic and copper rounds to an HI of 2, however, the individual HQs for arsenic and copper are less than 1. EPA guidance (EPA, 1989) suggests segregating non-cancer HQs by critical effect when the HI is greater than one if the individual chemicals have different effects and mechanisms of action. Because arsenic and copper have different critical effects and affect different target organs, a separate analysis of arsenic and copper indicates each metal has an HQ less than 1 for the two parcels in Hayden where the HIs are equal to 2. Therefore, based on the individual HQs, non-cancer health impacts are not expected for parcels 101-07-216 in Zone 1 and 101-09-088 in Zone 15 in Hayden. For these two parcels, summing the hazards may over-estimate potential non-cancer impacts because they do not have the same critical effect. All other parcels in Hayden with an HI of 2 or more have at least one HQ of 1 or greater. This observation does not occur for any parcel in Winkelman.

7.4.2 Bioavailability Factor

Arsenic is the only carcinogenic contaminant evaluated for residential surface soil exposures, and therefore, contributes all of the cancer risk reported for surface soils in Hayden and Winkelman. The estimated oral exposure and the final estimated cancer risk for arsenic are directly related to the arsenic oral bioavailability, which is the percentage of arsenic absorbed through the ingestion route. This is important since the oral route (i.e., incidental ingestion of soil) contributes approximately 90 percent of the total arsenic cancer risk associated with exposure to residential surface soil. For this risk assessment, an oral bioavailability of 80 percent was used for arsenic, which is consistent with the RME approach used for the exposure assumptions.

The screening-level soil lead concentrations estimated for residential soil for this HHRA are directly related to the assumed lead oral bioavailability. The Cal-EPA LeadSpread default oral bioavailability of 44 percent was used in the estimation of lead screening-levels for this HHRA. The Physically Based Extraction Test (PBET) results (i.e., bioavailable fraction) for lead for this Site range from 16 percent to greater than 100 percent (Appendix J). If the form of lead present at a particular property is more or less bioavailable than 44 percent, the screening-level may be over-estimated or under-estimated, respectively, for that property.

7.4.3 Non-Detected Chemicals

A comparison of reporting limits to the screening-levels for analytes not detected in RI samples was conducted. For details of this comparison, see Section 3 (Data Evaluation) of Volume I of the RI Report. When an analyte is not detected and the reporting limit exceeds the applicable screening-levels, some uncertainty regarding the presence of an exceedance exists. Since the analyte reporting limit is generally two to five times the MDL and positive results are reported to the MDL, the uncertainty is less in cases where the screening-level falls within this margin. When the screening-level is below the estimated MDL (range between one-half and one-fifth the reporting limit), a larger uncertainty regarding the presence of an exceedance exists.

For all methods, the reporting limits are consistent with the project plan. Notably, the ambient air and water screening-levels and EPA tap water PRGs are at concentrations below what can be achieved using the best available analytical methodologies.

7.5 Indoor and Attic Dust

Uncertainties associated with the evaluation of indoor and attic dust data, including uncertainties in the sampling and analysis of the dust samples, selection of chemicals of concern, and the use of soil screening-levels (Arizona R-SRLs) to evaluate the dust sampling results, is presented in this section.

Homes for sampling were selected based on concentrations of arsenic in soil detected during residential surface soil sampling activities in January and February 2006. The sample locations were selected to include several homes where relatively low, medium, and high concentrations of arsenic were found in soils. The indoor (occupied area) dust samples were collected from floors and other horizontal surfaces with preference given to areas that tend to collect dust (such as high window ledges, along baseboards, and behind furniture). A

fundamental assumption of this screening evaluation is that the dust from these locations is similar (in terms of chemical concentrations) to the dust that a household resident would be exposed to.

In Hayden, 18 of 301 habitable homes were sampled for dust. The homes were chosen to represent low, medium, and high concentrations of arsenic in soil, which is a small proportion of the total number of homes. However, indoor dust in almost all the sampled homes in Hayden had concentrations that exceeded the arsenic and copper Arizona R-SRLs and the lead Arizona R-SRL was exceeded in more than 40 percent of the sampled homes in Hayden. Attic dust samples in all of the nine Hayden homes had concentrations of metals that exceeded the arsenic, copper, and lead Arizona R-SRLs. Given the relatively large geographic area of sampling coverage, the results of the dust sampling in the Hayden homes may also be representative of the homes not sampled, but dust sampling of the other homes would provide confirmation.

In Winkelman, four of 146 habitable homes were sampled for dust. Concentration levels of arsenic in one indoor dust sample exceeded the Arizona R-SRL for arsenic, but not the Site-specific background soil level (12.5 mg/kg) for arsenic. The two attic dust samples collected in Winkelman exceeded the Arizona R-SRL and Site-specific background level for arsenic. Indoor and attic dust sample concentration did not exceed the Arizona R-SRLs for copper and lead. Winkelman is further than Hayden from current ASARCO operations, and lower dust sample concentrations are consistent with the lower soil concentrations found during the RI. The low levels of metals in dust samples may be representative of the homes not sampled, but dust sampling at the other homes will provide confirmation.

Indoor dust was collected from each home as a single composite sample using a handheld vacuum cleaner device. Dust sampling was directed and judgmental. Dust samples were purposely collected from areas that tend to accumulate dust, such as areas along baseboards, behind furniture, and high window ledges. Levels of arsenic, copper, and lead that exceeded Arizona R-SRLs were consistently found in Hayden, but not in Winkelman. It is unlikely that indoor dust metals levels were grossly over- or under-estimated for purposes of this screening-level evaluation.

Approximately half as many attics were sampled for dust at indoor locations. Attics in the homes of the desert communities of Hayden and Winkelman are typically only accessible through an access hatch in the ceiling by use of a ladder. Attic dust samples were collected from the closest accessible area near the hatch using a brush or putty knife. If the dust metal levels are evenly distributed in the attic, it is unlikely that indoor dust levels were grossly over- or under-estimated for purposes of this screening-level evaluation.

An additional uncertainty is the exposure to attic dust that residents might experience. Access to the attics is by ladder through an opening in the ceiling and vertical clearance in the attic is only three to four feet. Intentional exposure to the attic and attic dust would typically be only to retrieve or replace a few items stored in the attic a couple of times per year. Exposure would be greater during any remodeling, which might involve exposure to attic dust, but exposure during remodeling would be expected to be short term, as well. The only longer term exposures are assumed to be attic dust slowly shifting through cracks in the ceiling or drywall over time. The extent of this type of exposure in Hayden and Winkelman would need to be evaluated on a home by home basis.

The major COCs in soil identified in the RI report (Volume I) are arsenic, copper, and lead. Arsenic, copper, and lead are also identified in this dust evaluation as the major metals in indoor and attic dust. It is unlikely that any other major metal contaminants in dust were not identified.

Although the general association between soil and dust concentrations was not strong, the parcels with the highest concentrations of lead in indoor dust exceeded the lead concentrations in the surface soil samples for the parcel. Other non-site related sources of lead in the dust, such as lead-based paint, may be contributing to those high concentrations of lead.

Arizona R-SRLs are risk-based standards for contaminants in soil that were developed by ADEQ (ADEQ, 2008). Arizona R-SRLs are protective of human health, including sensitive groups, over a lifetime. In this screening assessment, the concentrations of metals in the dust samples are compared to Arizona R-SRLs, which are used as risk-based screening values for indoor and attic dust. Given that these soil screening-levels are intended to address potential exposure from direct contact with both exterior soil and indoor dust, comparing dust levels directly to Arizona R-SRLs may result in some conservatism.

The Arizona R-SRL for arsenic is an exception and is based on assumed background levels of soil arsenic in Arizona. The arsenic Arizona R-SRL is very close to the measured background soil level for arsenic for Hayden and Winkelman; therefore, it is also a reasonable screening-level.

8. Summary of Results

This section presents a summary of the potential cancer risks and non-cancer health hazards caused by exposure to site-related chemicals. The HHRA evaluated potential health risks and hazards to current and future receptors from exposure to COCs in soil, air, groundwater, surface water, sediment, and indoor and attic dust. Consistent with the CSM, the predominant exposure pathways for current and future residents are incidental ingestion, inhalation of particulates, and dermal contact with residential soil and inhalation of particulates in ambient air. This HHRA evaluates exposure to:

- Residential surface soil and ambient air for Hayden and Winkelman
- Non-residential surface soil data categorized into four main groupings: Hayden, Winkelman, ASARCO Properties, and Outlying Areas
- Surface water and sediments in the Gila and San Pedro Rivers

In addition, a screening-level quantitative risk evaluation was conducted on groundwater monitoring data that has been grouped by:

- Drinking water aquifer
- Non-drinking water aquifer
- Hayden municipal supply well and manifold
- Winkelman municipal supply well and manifold
- Tap water from the Hayden Library and Winkelman Elementary School

Finally, a qualitative risk evaluation was conducted on:

- Indoor and attic dust from homes in Hayden and Winkelman

The objectives of this HHRA were to:

- Evaluate potential cancer risks and non-cancer hazards posed by Site-related chemicals in residential surface soil and ambient air to adult and child receptors, under conditions of residential land use.
- Evaluate potential cancer risks and non-cancer hazards posed by Site-related chemicals in non-residential surface soil to adult and/or child receptors, under trespassing/recreational/residential use.
- Evaluate potential screening-level cancer risks and non-cancer hazards posed by Site-related chemicals in groundwater to adult and child residents.
- Evaluate potential cancer risks and non-cancer hazards posed by Site-related chemicals in surface water and sediments to adult and child receptors, under recreational use.
- Identify chemicals, media, and pathways that are of the greatest concern, and to assess whether cancer risks or non-cancer hazards are unacceptable.

The Site is an active copper ore processing, concentrating, and smelter facility located in Gila County, Arizona, near the confluence of the Gila River and San Pedro River. The active portion of the Site consists of ASARCO's crusher, concentrator, smelter, and tailings

impoundment areas. The study area encompasses the town of Hayden, the town of Winkelman, and the ASARCO-owned and operated ore processing operation.

Each of the main portions of the study area was divided into exposure areas that are representative of areas contacted by receptors on a regular basis. The exposure areas were evaluated for potential cancer risks and non-cancer hazards to adult and child receptors under residential and non-residential land use (including trespasser and recreational scenarios). The exposure routes evaluated included direct contact with soil (incidental ingestion, dermal contact) and outdoor inhalation of dusts in ambient air. This HHRA achieves the objectives described above through the following activities:

- Cancer risks and non-cancer hazards are estimated based on EPA risk assessment guidance and methodology, and site-specific risk assessment exposure assumptions.
- Risks and hazards associated with COCs in soil for each exposure area, and COCs in surface water and sediment are estimated by performing risk and hazard calculations. Screening-level risks and hazards associated with COCs in groundwater are estimated by performing "risk ratio" risk and hazard calculations using EPA Region 9 tap water PRGs. The risks and hazards for all the COCs are separately summed, by medium, to estimate the cumulative risk and HI for each exposure area.
- Locations at which cumulative risks exceed the EPA risk management range of 10^{-6} to 10^{-4} or the HI exceeds 1 are identified. Chemicals and media contributing to unacceptable cancer risk and hazard levels are identified.
- Site-specific exposure assumptions were identified that can be used as inputs for calculating risk-based concentrations for assisting with remedial decisions; additionally, background levels were established for metals in soil that also will aid in remedial decisions.

8.1 Soil Removal

Subsequent to the collection of the residential soil samples, a soil removal action was conducted under an agreement signed in March 2008. ASARCO performed and paid for removal of contaminated soil at 15 privately owned residential parcels in Hayden and Winkelman. This cleanup work was conducted with oversight from EPA, and took place between late March and early June 2008. EPA reviewed the residential soil sample data from the RI (as presented in Section 4.1 of this report) and decided to promptly address those residential yards where the highest concentrations of arsenic, copper, and lead were found. Yards where soil contamination levels exceeded 200 mg/kg of arsenic, 2,000 mg/kg of lead, or 20,000 mg/kg of copper were selected for cleanup. Based on these soil concentration levels, the following 14 properties in Hayden were selected by EPA and then cleaned up by ASARCO:

1. 101-07-035AS
2. 101-07-040
3. 101-07-066
4. 101-07-089Q
5. 101-07-089S
6. 101-07-089T

7. 101-07-091
8. 101-09-004
9. 101-09-036
10. 101-09-039
11. 101-09-070
12. 101-09-077
13. 101-09-088
14. 101-09-140

In Winkelman, one residential yard (101-12-149) was selected by EPA and then cleaned up by ASARCO.

The soil cleanup activities consisted of removing the top one to two feet of soil, replacing it with clean fill, regrading the area, and adding a stabilizing sod cover. The interiors of some of the homes also were addressed. As a result of the soil removal activities, the soil samples collected during the RI at these parcels are no longer representative of soil conditions at these properties. Following is a discussion of the condition of the properties under baseline conditions – before the removal action. Therefore, risks/hazards associated with soil exposure at the 15 parcels where the removal action occurred are no longer present as described because of the clean fill and stabilizing sod cover.

8.2 Residential Soil

Out of the 130 residential properties evaluated, potential risks to residents due to direct contact with soil exceeded the EPA risk management range of 10^{-6} to 10^{-4} for six parcels in Hayden and one parcel in Winkelman. Eighty-three (83) of the parcels in Hayden and Winkelman have lead concentrations that exceed the site-specific screening-level of 212 mg/kg.

8.2.1 Residential Parcels in Hayden

In Hayden, residential cancer risk and non-cancer hazard estimates are presented for the 99 residential parcels sampled.

- Six parcels have ELCRs that exceed EPA's risk management range, while 93 have estimated ELCRs that fall within EPA's risk management range, although they are all at the upper end of the EPA risk management range (between 10^{-5} to 10^{-4}). The six parcels that exceed include: 101-07-176, 101-07-089K, 101-07-089T, 101-07-034, 101-09-038, and 101-07-140.
- For non-cancer effects, 91 parcels show an HI that exceeds the non-cancer threshold of 1, and eight parcels have an HI that does not exceed that threshold. The HIs that exceed the threshold range from 2 to 27.
- Elevated levels of lead are widespread in Hayden. Seventy-two (72) of the parcels evaluated had lead concentrations that exceed the site-specific screening-level of 212 mg/kg, which excludes the homegrown produce pathway.

8.2.2 Residential Parcels in Winkelman

In Winkelman, residential soil results include the cancer risk and non-cancer hazard estimates for 31 residential parcels.

- Only one parcel (101-12-071) has an estimated ELCR (2×10^{-4}) that exceeds the EPA risk management range.
- For non-cancer effects, three parcels have an HI that exceeds the non-cancer threshold of 1. The HIs for these three parcels range from 3 to 4.
- Eleven of the 31 parcels evaluated have lead concentrations that exceed the site-specific screening-level of 212 mg/kg.

8.3 Non-Residential Soil

The non-residential soil exposure areas include six areas in Hayden, four areas in Winkelman, 14 areas associated with the ASARCO Properties, and 11 areas in Outlying Areas. Following is a brief summary of the HHRA results.

8.3.1 Non-Residential Exposure Areas in Hayden

In Hayden, non-residential cancer risk and non-cancer hazard estimates are presented for the six exposure areas, which include the Hayden Public Areas, the Hayden Golf Course (divided into two subareas), and the San Pedro Wash, Kennecott Avenue Wash, and Power House Wash. The receptors evaluated for these exposure areas include a child playing at the park, an adult golfer, and a child and adult trespasser (using in-town exposure assumptions).

- All six exposure areas have estimated ELCRs that are within the EPA risk management range. Of these six exposure areas, five exposure areas are within and one exposure area is below the risk management range.
- For non-cancer effects, two exposure areas have an HI that exceeds the non-cancer threshold of 1. The HIs that exceed range from 2 (Power House Wash) to 4 (Community Library/Park).
- All six exposure areas have a lead EPC less than the site-specific risk-based screening-level of 212 mg/kg, which excludes the homegrown produce pathway.

8.3.2 Non-Residential Exposure Areas in Winkelman

In Winkelman, non-residential cancer risk and non-cancer hazard estimates are presented for the four exposure areas, which include the Winkelman School complex and three residential properties associated with the school. These three properties/trailers are on school property; however, as a conservative estimate of risk, the residential exposure scenario was used to evaluate these properties. A school child scenario was used for the Winkelman School complex exposure area.

- All four exposure areas have estimated ELCRs that are within the EPA risk management range. The range of ELCRs is from 5×10^{-6} to 2×10^{-5} .

- For non-cancer effects, all four exposure areas have HIs that do not exceed the non-cancer threshold of 1.
- All four exposure areas have a lead EPC less than the site-specific risk-based screening-level of 212 mg/kg.

8.3.3 Non-Residential Exposure Areas in ASARCO Properties

In ASARCO Properties groupings, non-residential cancer risk and non-cancer hazard estimates are presented for the 14 exposure areas:

- Kennecott Smelter – North End
- Kennecott Smelter Basin
- Kennecott Smelter Plant
- Kennecott Smelter – Lime Plant
- Kennecott Smelter – South of Lime Plant
- West of Administration Building
- Thickener Tank Area
- South of Concentrator
- South of Mill Building
- East of Hillcrest Avenue
- North of Mill Building
- 5th Street Right-of-Way
- Crusher Facility
- Conveyor Drainage Tailings

The five subareas located around the Kennecott Smelter were evaluated for a remote trespasser; and the nine subareas located on the west side of the town Hayden were evaluated for an in-town trespasser. A brief summary of the results follows.

- Only one exposure area (East of Hillcrest Avenue) has an estimated ELCR (2×10^{-3}) that exceeds the EPA risk management range.
- For non-cancer effects, 13 exposure areas have HIs that exceed the non-cancer threshold of 1. For the exposure areas that exceed the threshold, HIs range from 2 to 28.
- Seven exposure areas have a lead EPC that exceeds the site-specific risk-based screening level of 212 mg/kg.

8.3.4 Non-Residential Exposure Areas in Outlying Areas

In the outlying area, non-residential cancer risk and non-cancer hazard estimates are presented for the 11 exposure areas, including:

- Tertiary Sediments – South of Smelter
- Slag Dump
- State Route 77
- Tailings Impoundment AB/BC
- Tailings Impoundment D
- Older Quaternary Deposits – North of Hayden
- Cretaceous/Tertiary Intrusives and Volcanics

- Tertiary Sediments – South of Winkelman
- Quaternary Alluvium
- Older Quaternary Deposits – North of Tailings Impoundment D
- Tertiary Sediments – West of Concentrator

The remote trespasser bike-riding youth and occasional hiking adult were evaluated for these areas.

- All 11 exposure areas have estimated ELCRs are within the EPA risk management range.
- For non-cancer effects, only one exposure area (Slag Dump) has an HI (31) that exceeds the non-cancer threshold of 1.
- Three exposure areas have a lead EPC that exceed the site-specific risk-based screening-level of 212 mg/kg for lead.

8.4 Air

The potential risks and hazards associated with exposure to ambient air include both resuspension of particulates and smelter emissions. Cancer risk and non-cancer hazard estimates are presented for the RI air monitoring stations in Hayden and Winkelman.

8.4.1 Hayden

- The ELCR associated with the ambient air monitoring data in Hayden is 1×10^{-4} , which is at the upper end of EPA's risk management range. The primary contributor to risk is arsenic.
- The EPC for copper of $1.3 \mu\text{g}/\text{m}^3$ from the Hayden air monitoring station is above background levels. The EPC for lead of $0.183 \mu\text{g}/\text{m}^3$ is less than the EPA NAAQS of $1.5 \mu\text{g}/\text{m}^3$ and within the range of EPA's proposed revision to the NAAQS for lead of 0.1 to $0.3 \mu\text{g}/\text{m}^3$ (EPA, 2008d).

8.4.2 Winkelman

- The ELCR associated with the Winkelman ambient air monitoring data is 4×10^{-5} , which is within EPA's risk management range.
- The EPC for copper of $0.36 \mu\text{g}/\text{m}^3$ from the Winkelman air monitoring station is above background levels.
- The Winkelman 95 percent UCL for lead of $0.028 \mu\text{g}/\text{m}^3$ is less than the EPA NAAQS of $1.5 \mu\text{g}/\text{m}^3$ and below the range of EPA's proposed revision to the NAAQS for lead of 0.1 to $0.3 \mu\text{g}/\text{m}^3$ (EPA, 2008d).

8.5 Groundwater

A quantitative screening-level evaluation was conducted for residential exposure to groundwater at Hayden and Winkelman. For this screening-level evaluation, the “risk ratio” approach was used where the concentrations of constituents in groundwater are compared to EPA Region 9 tap water PRGs and radionuclide PRGs from EPA’s ORNL website (EPA, 2008).

8.5.1 Drinking Water Aquifer

- The drinking water aquifer has an estimated screening-level ELCR of 2×10^{-4} which exceeds the EPA risk management range.
- For non-cancer effects, the drinking water aquifer screening-level HI of 7 which exceeds the non-cancer threshold of 1.
- For radionuclides, the drinking water aquifer has an estimated screening-level ELCR of 5×10^{-4} which exceeds the EPA risk management range.

8.5.2 Non-Drinking Water Aquifer

- The non-drinking water aquifer which is located beneath industrial areas has an estimated screening-level ELCR of 4×10^{-3} which exceeds the EPA risk management range.
- For non-cancer effects, the non-drinking water aquifer screening-level HI of 35 which exceeds the non-cancer threshold of 1.
- For radionuclides, the non-drinking water aquifer has an estimated screening-level ELCR of 4×10^{-4} which exceeds the EPA risk management range.

8.5.3 Hayden Municipal Supply Well and Manifold

- The Hayden municipal supply well and manifold has an estimated screening-level ELCR of 9×10^{-5} that is within the EPA risk management range.
- For non-cancer effects, the Hayden municipal supply well and manifold screening-level HI of 2 which exceeds the non-cancer threshold of 1.
- For radionuclides, the Hayden municipal supply well and manifold has an estimated screening-level ELCR of 6×10^{-4} which exceeds the EPA risk management range.

8.5.4 Winkelman Municipal Supply Well and Manifold

- The Winkelman municipal supply well and manifold has an estimated screening-level ELCR of 1×10^{-4} which is at the upper end of the EPA risk management range.
- For non-cancer effects, the Winkelman municipal supply well and manifold screening-level HI of 2 which exceeds the non-cancer threshold of 1.
- For radionuclides, the Winkelman municipal supply well and manifold has an estimated screening-level ELCR of 5×10^{-6} which is within the EPA risk management range.

8.5.5 Tap Water

- Tap water samples from the Hayden Library and Winkelman School has an estimated screening-level ELCR of 1×10^{-4} for each location which is at the upper end of the EPA risk management range.
- For non-cancer effects, the tap water screening-level HI exceeds the non-cancer threshold of 1.
- For radionuclides, tap water from Hayden has an estimated screening-level ELCR of 4×10^{-6} which is within the EPA risk management range and from Winkelman the ELCR of 4×10^{-6} is below the range.

8.5.6 Background Concentrations of Metals and Radionuclides

The primary chemical contributor to risk for each of the groundwater data groupings is arsenic. Because there is no Site-specific background groundwater quality study, arsenic EPCs were compared to local groundwater background levels from monitoring wells in Maricopa County, which is adjacent and just west of Gila County. According to the USGS NAWQA Data Warehouse, arsenic groundwater concentrations range from 1 to 81 $\mu\text{g}/\text{L}$ (USGS, 2008). The county groundwater data were collected between 1997 and 2007. The average arsenic groundwater concentration in Maricopa County is 13 $\mu\text{g}/\text{L}$. The arsenic EPCs for the four exposure groupings evaluated range from 4 to 7.4 $\mu\text{g}/\text{L}$ which are generally below the NAWQA background levels. The only arsenic EPC that is substantially higher than the background level is from the non-drinking water aquifer data grouping (175 $\mu\text{g}/\text{L}$). The range of arsenic EPCs in the other groupings is 3.98 $\mu\text{g}/\text{L}$ from the Hayden Municipal Supply Wells to 7.41 $\mu\text{g}/\text{L}$ from the Drinking Water Aquifer Supply Wells. These EPCs are less than the arsenic MCL of 10 $\mu\text{g}/\text{L}$.

The primary radionuclide contributor for the drinking water aquifer, non-drinking water aquifer, and Hayden municipal supply well and manifold sample data groupings is Radium 226. The cumulative risks for these data groupings range from 4×10^{-4} to 6×10^{-4} . EPA regulates Radium 226 in drinking water and promulgated an MCL of 5 pCi/L in 1975 (EPA, 2008c). All of the Radium 226 EPCs are well below the MCL of 5 pCi/L (Site EPCs range from 0.3 to 0.5 pCi/L). Because there is no Site-specific background groundwater quality study for radionuclides, the EPCs for Radium 226 were compared to the national median concentration of 0.39 pCi/L (USGS, 1998). The range of Radium 226 radioactivity in the four groundwater groupings is 0.3 to 0.8 pCi/L (both the minimum and maximum concentrations are from the Drinking Water Aquifer data grouping). The national maximum concentration was approximately 15 pCi/L. The Radium 226 EPCs are within the range of national background concentrations.

8.6 Surface Water – Gila River and San Pedro River

Surface water samples were collected during two sampling events from locations along the Gila River and San Pedro River. The two events occurred in the winter (March 7 and 8, 2006) and the summer (August 22 and 23, 2006). Surface water samples were collected at 11 locations along the Gila River and two locations along the San Pedro River. Adult and child recreational users (swimmers) were evaluated for exposure to surface water.

- Surface water has an estimated ELCR that does not exceed the EPA risk management range.
- For non-cancer effects, the surface water HI does not exceed the non-cancer threshold of 1.

8.7 Sediment – Gila River and San Pedro River

In-stream sediment samples were collected during two events from locations along the Gila River and San Pedro River. These samples were collected concurrently with the surface water samples during two sampling events. Sediment samples were collected at 11 locations along the Gila River and two locations along the San Pedro River. Adult and child recreational users (anglers) were evaluated for exposure to sediment.

- Sediments have an estimated ELCR that does not exceed the EPA risk management range.
- For non-cancer effects, the sediment HI does not exceed the non-cancer threshold of 1.
- Sediments have a lead EPC that does not exceed the site-specific risk-based screening-level of 212 mg/kg.

8.8 Indoor and Attic Dust

A qualitative analysis was conducted on the dust sampling results. A comparison was made of the dust results to the results from the soil samples collected in the yards of the 22 homes where indoor and attic dust was collected.

8.8.1 Hayden

Of the 301 habitable homes in Hayden, indoor dust was sampled in 18 homes and attic dust was sampled in nine homes with accessible attics. The screening comparison to Arizona R-SRLs for metals showed that:

- The arsenic Arizona R-SRL of 10 mg/kg was exceeded in 16 of 18 indoor dust samples.
- The copper Arizona R-SRL of 3,100 mg/kg was exceeded in 14 of 18 indoor dust samples.
- The lead Arizona R-SRL of 400 mg/kg was exceeded in eight of 18 indoor dust samples.
- All nine attic dust samples collected in Hayden had concentrations of metals that exceeded the Arizona R-SRLs for arsenic, copper, and lead.
- Limited Arizona R-SRL exceedances were found for other metals, which included cadmium (two of 18 indoor dust samples); and aluminum, antimony, vanadium, and zinc (one of 18 indoor dust samples each).

Although a limited number of homes were sampled for both indoor dust and attic dust in Hayden, the data indicate that Arizona R-SRLs for arsenic, copper, and lead are exceeded by

all attic dust samples, and one attic dust sample had a cadmium concentration above the Arizona R-SRL.

8.8.2 Winkelman

Of the 146 habitable homes in Winkelman, four homes were sampled for indoor dust and the two homes with accessible attics were sampled for attic dust. The screening comparison to Arizona R-SRLs for metals showed that:

- The arsenic Arizona R-SRL of 10 mg/kg was slightly exceeded (10.2 mg/kg) in one of four indoor dust samples. However, all the indoor dust samples have arsenic results that are below the Winkelman site-specific background level for arsenic of 12.5 mg/kg.
- Both attic dust samples exceeded the Arizona R-SRL and site-specific background level for arsenic.
- No indoor or attic dust samples exceeded the copper or lead Arizona R-SRLs.
- One indoor and one attic dust sample had antimony concentrations above the Arizona R-SRL.

In summary, arsenic is the main COC in Winkelman dust samples, although levels above the Arizona R-SRLs and site-specific background levels are limited to attic dust samples.

8.9 Multi-Pathway Cumulative Risks – Soil and Air

As a means of evaluating multi-pathway cumulative risks and comparing the relative contribution to risk from multi-pathway exposures, the sum of the residential soil and ambient air cancer risks were calculated for three different representative soil and ambient air exposure combinations for both Hayden and Winkelman.

- Example 1 (Background). The sum of soil background risk plus air monitoring background risks.
- Example 2 (Mid-Level Soils Concentrations). The sum soil risks for 5×10^{-5} cancer risk corresponding to 26 mg/kg arsenic in Hayden (20 mg/kg arsenic, 4×10^{-5} risk, in Winkelman), plus the corresponding air monitoring risks.
- Example 3 (High-Level Soils Concentrations). The sum of soil risks for the highest concentration property (assumed highest level of soil arsenic after forthcoming remediation of properties): 132 mg/kg arsenic in Hayden, 112 mg/kg arsenic in Winkelman) plus air monitoring risks.

8.9.1 Hayden

For Hayden, the sum of residential soil plus ambient air cancer risk was 3×10^{-5} (Example 1), 2×10^{-4} (Example 2) and 4×10^{-4} (Example 3). Ambient air cancer risks were 1×10^{-4} ; all additional incremental risks are assumed to be due to residential soil exposure in Hayden.

8.9.2 Winkelman

For Winkelman the sum of residential soil plus ambient air cancer risk was 3×10^{-5} (Example 1), 8×10^{-5} (Example 2), and 2×10^{-4} (Example 3). Ambient air cancer risks were 4×10^{-5} ; all additional incremental risks are assumed to be due to residential soil exposure in Winkelman.

9. Conclusions

The HHRA results indicate that the current and former ASARCO operations have resulted in measurable impacts to soils, ambient air, and indoor dust, and to a lesser extent on groundwater, surface water and sediment. In addition, excess lifetime cancer risks exceed EPA's risk management range for some residential and nonresidential properties. Data gaps have been identified related to environmental media sampling (see Section 7.5 of Volume I the RI Report) and therefore, additional studies will be needed to fill those data gaps.

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Tables

Figures

Appendix A

Residential Soil Risk Calculations and Summary Tables

Appendix B

Nonresidential Soil Risk Calculations and Summary Tables

Appendix C Ambient Air Risk Calculations and Summary Tables

Appendix D

Groundwater Risk Calculations and Summary Tables

Appendix E

Surface Water Risk Calculations

Appendix F
Sediment Risk Calculations

Appendix G
Graphs Comparing Concentrations
of Metals in Dust to Metals in Soil

Appendix H
Background Risk Calculations and Graphs
Comparing Background Risks to Residential Risks

Appendix I
Notes from Interview with Winkelman Resident
Regarding Exposure Assumptions

Appendix J
Results of Mineral Speciation and Physically Based
Extraction Test (PBET)

Appendix K
Handouts from EPA's Open House and Community Meeting,
January 9, 10, 2008

Appendix L
ATSDR ToxFAQs for Chemicals of Concern
