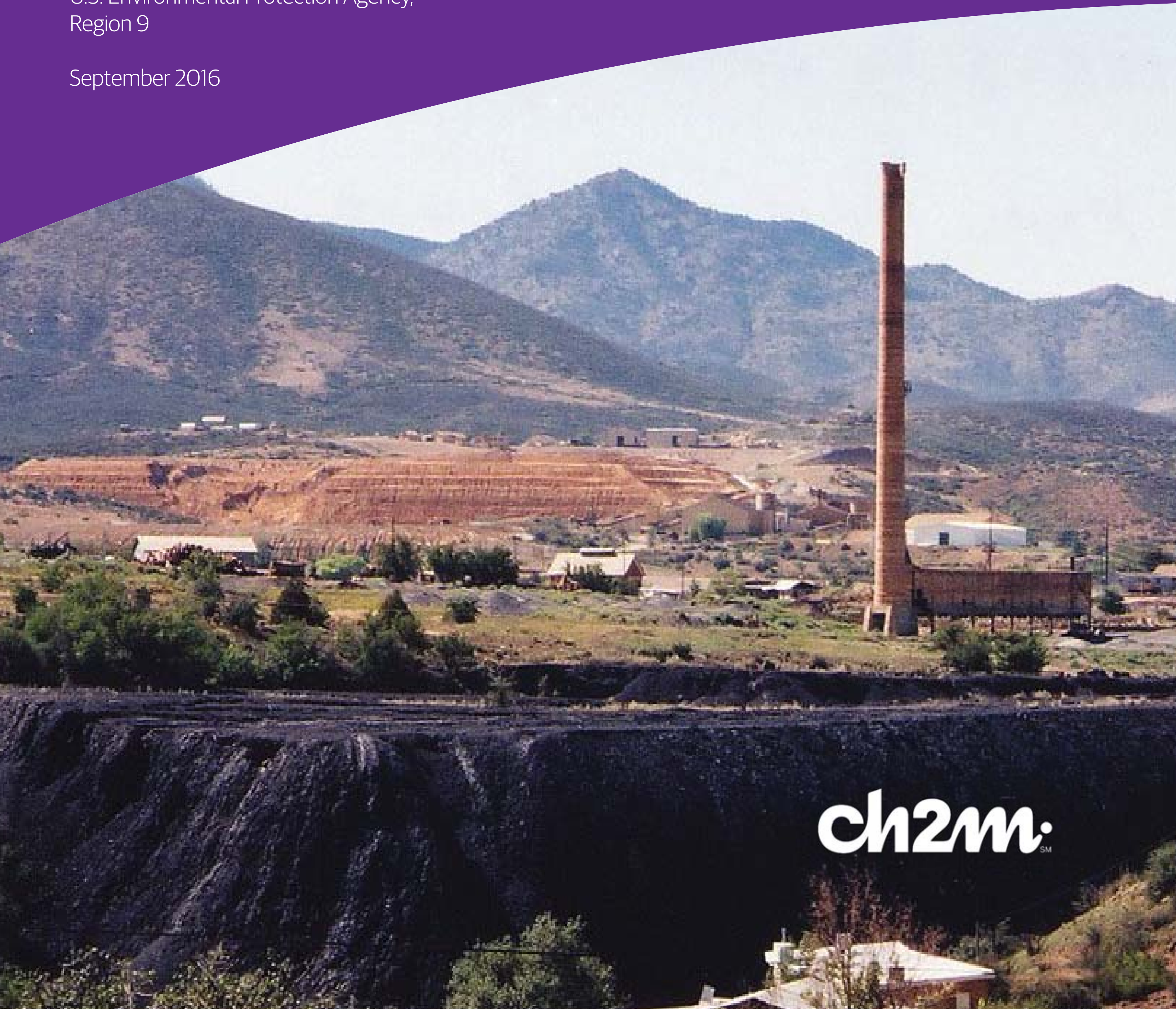
Remedial Investigation Report

Iron King Mine – Humboldt Smelter Superfund Site

Dewey-Humboldt, Yavapai County, Arizona

Prepared for
U.S. Environmental Protection Agency,
Region 9

September 2016



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Executive Summary

The U.S. Environmental Protection Agency (EPA), under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended, has completed a remedial investigation (RI) of the Iron King Mine – Humboldt Smelter Superfund Site (the Site), located in Dewey-Humboldt, Yavapai County, Arizona. The objective of the RI is to characterize conditions at the Site, determine the nature and extent of site-related contamination, evaluate how and why the contamination was distributed and may continue to migrate if not addressed, and assess potential current and future risks to human health and the environment.

This Executive Summary presents the key findings and results of the *Remedial Investigation Report, Iron King Mine – Humboldt Smelter Superfund Site, Dewey-Humboldt, Yavapai County, Arizona,* dated September 2016 (RI Report). The Executive Summary provides an introduction to the Site, an overview of investigations conducted including data collection and evaluation, a summary of findings pertaining to the nature and extent of contamination, a summary of the risks to human health and the environment, and considerations for the path forward and next steps in the CERCLA process.

Site Description

The former Iron King Mine and Humboldt Smelter properties lie within the current boundary of the Town of Dewey-Humboldt (Figure ES-1). The town, which covers an area of about 19 square miles (or 12,000 acres), is located at the southeastern end of the Lonesome Valley, and at an elevation of about 4,600 feet, in the high desert of central Arizona, about 85 miles north of Phoenix. State Highway 69 transects the town north to south. The Agua Fria River, the primary surface water feature in this part of the Lonesome Valley, also transects the town from north to south, east of Highway 69. The former Iron King Mine property, where mining operations began in the late 1890s, consists of about 150 acres and is located west of Highway 69. The former Humboldt Smelter property, where mining and smelting operations began in the late 1870s, consists of about 180 acres and is located about 0.5 mile east of Highway 69. The Agua Fria River flows south through portions of the eastern section of the former Humboldt Smelter property (Figure ES-1).

The Town of Dewey-Humboldt was incorporated in 2004, combining the historical communities of Dewey and Humboldt (shown as Dewey Proper and Humboldt Proper on Figure ES-1). The Humboldt area economy was based on mining, whereas the economy of Dewey was based on agriculture and ranching. Existing land uses within the Town of Dewey-Humboldt include small farms, some higher-density urban development with adjacent commercial uses, and single-family residential neighborhoods (Town of Dewey-Humboldt, 2009). Adjoining the town to the west is the Prescott National Forest (Figure ES-1).

In the vicinity of the Site, the Agua Fria River is perennial and has designated uses of domestic water source, full body contact (swimming), fish consumption, agricultural irrigation, agricultural livestock watering, and warm water aquatic and wildlife. The primary source of domestic water for the town, however, is via water rights from private exempt wells (less than 35 gallons per minute each); 80 percent of the town residents rely on private wells. The remaining residents are provided water from groundwater supply wells operated by private water companies including Humboldt Water Company, which services the south-central portion of the town near the Site, and the Wilhoit Water Company, which services the north-central portion of the town (ADEQ, 2006; Town of Dewey-Humboldt, 2009; E2 Inc., 2010).

The Site consists of a combination of contaminant sources, originating from operations at the former Iron King Mine and the former Humboldt Smelter, and areas to which contamination has come to be located. EPA combined the properties and contamination from the properties into one CERCLA site because of their proximity, because the respective operations involved the same types of potentially hazardous materials and contaminant sources, and because they resulted in commingled contamination in storm drainages and in the surrounding town.

Regulatory History and Site Investigations

Formal concerns related to the accumulated contamination at the former Iron King Mine and Humboldt Smelter properties began as a result of EPA and Arizona Department of Environmental Quality (ADEQ) involvement in the various air quality, stormwater, landfill operation, and wastewater treatment permits held by facility operators. Complaints were documented and permit compliance violations reported. EPA and/or ADEQ performed the first CERCLA investigations (preliminary assessment/site inspections) at the properties in 2002-2004. A removal assessment was completed by EPA in 2005, and an expanded site inspection was completed by EPA in 2006.

The principal findings of these investigations were that hazardous materials, primarily metals, had been released at the former Iron King Mine and former Humboldt Smelter properties (or adjacent properties), and the contaminant sources included the following:

- The Main Tailings Pile (MTP) at the former Iron King Mine property (exacerbated by the "MTP 1964 Blow Out" during which a large portion of the MTP slumped and some of the finer-grained tailings released from the pile were transported east of State Highway 69 through the area now occupied by the JT Septic Facility, the drainage adjacent to Third Street, and the Upper Chaparral Gulch)
- The Small Tailings Pile (now the former Small Tailings Pile, because it was removed in 2011) north of the former Iron King Mine property and adjacent to a small drainage tributary to Chaparral Gulch
- Waste rock at the former Iron King Mine property
- Tailings, ash (dross), and slag at the former Humboldt Smelter property
- Sediments in Chaparral Gulch and Galena Gulch

The locations of these and other Site features are shown on Figure ES-2. Detail is provided on Figure ES-3 for the former Iron King Mine property and Figure ES-4 for the former Humboldt Smelter property.

The findings of the initial investigations formed the basis for listing of the combined Iron King Mine – Humboldt Smelter Superfund Site on EPA's National Priorities List (NPL) on September 3, 2008.
In addition, two removal actions were performed at residential and municipal properties in response to the detection of concentrations of arsenic and lead in surface soil exceeding site-specific action levels set by EPA. The first removal action was performed in 2006-2007 by a property owner/operator, Ironite Products Company, and the second removal action was performed by EPA in 2011.

Following listing of the Site on the NPL in 2008, EPA performed the following four phases of investigations between 2008 and 2015:

Phase	Investigation Name	Performed by
Phase 1	2008 to 2009 Initial RI	Performed by EPA's contractor EA Engineering, Science, and Technology, Inc. (EA, 2010)
Phase 2	2010 and 2012 Supplemental RI	Performed by EPA's contractor EA Engineering, Science, and Technology, Inc. (EA, 2011)
Phase 3	2012 to 2013 Background and Surface Soil Sampling	Performed by EPA Region 9 (EPA, 2012b, 2012c)
Phase 4	2013 to 2015 Data Gap RI	Performed by EPA's Environmental Response Team and their contractor Lockheed Martin Scientific, Engineering, Response and Analytical Services (Lockheed Martin SERAS, 2015)

This RI Report provides a synthesis of the previous and current investigations and provides additional analysis, evaluation, and risk assessment conducted in 2015 and 2016.

Exposure Areas

The nature and extent of contaminants in surface water, sediment, groundwater, and ambient air are generally evaluated on a sitewide basis in this RI Report. For soil, however, EPA subdivided the Site into distinct human health and ecological exposure areas based on types of source materials, current or future land use, and property boundaries to facilitate the definition of the nature and extent of soil contamination, and the assessment of potential risk.

For the evaluation of human health risk, exposure areas defined for soil were given one of four designations based on current or potential future land use:

1. **Non-Residential.** Includes properties currently zoned for industrial, commercial, or recreational uses, or properties that are undeveloped and unlikely to be developed for residential use in the future.
2. **Non-Residential/Possible Future Residential.** Includes properties that are currently vacant or have a non-residential use, but could be rezoned and/or developed for residential use in the future.
3. **Residential Yard-Specific Risk (RYSR).** Residential properties sampled and evaluated on a yard-by-yard basis.
4. **Residential Screening Area Risk (RSAR).** Residential properties sampled and evaluated by screening areas, rather than individual yards.

For the evaluation of ecological risk, distinct exposure areas were defined for soil, surface water, and sediment. Exposure areas are shown on Figure ES-5.

Summary of Data Collection and Evaluation Approach

The investigations described in this RI Report involved collection and analysis of samples across the Site and surrounding areas, and a detailed evaluation of the results of those samples as well as observations made throughout the course of each investigation. A summary of the data collected, the data evaluation approach, and the key evaluation methods developed for this Site are provided in the following paragraphs.

Data Collection

The media sampled during the various investigations associated with the Site included:

- Surface soil
- Subsurface soil
- Sediment
- Surface water
- Groundwater
- Ambient air

Samples also were collected of waste rock, tailings, slag, and dross (classified as either "soil" or "sediment," depending on their location in waste piles or streambeds). The resulting database is extensive, including results from 9,478 soil samples, 254 sediment samples, 167 surface water samples, 339 groundwater samples, and 278 air samples. The majority (96 percent) of these samples were collected during the four phases of the RI. Thirty-one percent of the samples were collected from the former mine/smelter properties and adjacent areas, from non-residential properties, or from Chaparral Gulch. Sixty-nine percent were from residential areas.

Data Evaluation

The data evaluation process consisted of the following key steps:

1. Review of available data to determine its usability for evaluating the nature and extent of contaminants, and for assessing risk.
2. Estimation of background concentrations for surface soil and identification of the area of potential site impact (APSI), shown on Figure ES-2.
3. Identification of media-specific screening levels used to identify chemicals of interest (COIs) and delineate the nature and extent of contamination.
4. Comparison of analytical results to background concentrations and media-specific screening levels to identify preliminary COIs. Preliminary COIs are chemicals with concentrations that exceed screening levels in at least one sample and exceed background concentrations, if defined.
5. Identification of primary COIs for analyte groups and media based on the number of screening level exceedances, the magnitude of screening level exceedances, and the distribution of concentrations relative to Site source areas.
6. Site-specific analysis of geochemical signatures including (a) key metals concentrations for lead, copper, and zinc; and (b) the ratio of lead to copper and zinc to copper concentrations, to assist with the evaluation of the origin, fate, and transport of contaminants.
7. Grouping of sample results into exposure areas based on geographic boundaries, media, and potential exposures.
8. Evaluation of the distribution of the representative COIs for each analyte group and media, and estimation of the volume of source materials.

Area of Potential Site Impact, Screening Levels, and Chemicals of Interest

Area of Potential Site Impact

The soil background study (CH2M, 2015) performed as part of this RI (and included as Appendix E) focused on using site-related indicator parameters (copper and zinc) and ratios of shallow to deep metals concentrations to differentiate between site-affected areas and background areas. This approach allowed the calculation of defensible background concentrations for arsenic, lead, copper, and zinc; it also established an approximate geographic extent of potential site-related impacts, referred to as the APSI, that bounded the extent of the investigation during the data gap investigation. The APSI was determined by a rigorous and statistically based analysis of metals concentrations in soils spatially distributed up to 3 miles distant from the former mine and smelter operations. The APSI was based on several independent lines of evidence; its derivation is described in detail in Appendix E. In 2015, after completion of the soil background study, background concentrations were developed for an expanded list of metals and metalloids, primarily in support of the risk assessments, but also for use in the nature and extent evaluation.

Screening Levels

Screening levels are intended to provide a perspective for identifying the nature and extent of contamination. They are not intended to infer the existence or absence of unacceptable risk, since they do not address cumulative risk or consider contributions from background levels (the risk assessments described later in this executive summary provide site-specific estimates of risk intended for management decision making). The screening levels used for evaluating nature and extent in this RI were media-specific:

- Soil screening levels were based on the EPA Regional Screening Levels (RSLs) (EPA, 2015a) for residential soil exposures. Lead concentrations in soil were screened against both the residential RSL of 400 milligrams per kilogram (mg/kg) and a provisional (that is, not yet formally adopted) residential RSL of 140 mg/kg (EPA, 2015a). Potential soil COIs were identified as parameters with soil concentrations that exceed both the screening level and background concentration, where available.
- Sediment screening levels were selected from benchmarks that are commonly intended to address potential toxicity to benthic organisms that exist in aquatic habitats.
- Surface water screening levels were selected as the lowest of the ambient water quality criteria for protection of aquatic life.
- Groundwater screening levels included EPA primary drinking water maximum contaminant levels (MCLs), EPA secondary MCLs, Arizona Aquifer Water Quality Standards, and EPA tap water RSLs. The secondary MCLs, Arizona Aquifer Water Quality Standards, and tap water RSLs were used for chemicals that do not have primary MCLs.
- Ambient air screening levels were selected from residential RSLs.

Chemicals of Interest

The concentration of chemicals detected in site media were compared to the screening levels to identify preliminary COIs and delineate their extent for soil, sediment, surface water, groundwater, and ambient air. The list of preliminary COIs was further refined to identify primary COIs to be the focus of the nature and extent evaluation. Primary COIs for each media were selected with consideration of the following:

- Frequency of detection above screening levels
- Maximum concentrations relative to screening levels
- Distribution at the former Iron King Mine and Humboldt Smelter properties and adjacent areas

Primary COIs identified for the various media included:

- For soil: arsenic and lead. In addition, although not primary COIs, zinc and copper are also used as key indicators for evaluating the nature and extent of sitewide soil contamination and the fate and transport of tailings because, together with lead, they are diagnostic of materials being from either the former Iron King Mine or Humboldt Smelter.
- For sediment: arsenic, copper, lead, mercury, and zinc.
- For surface water: arsenic, copper, iron, lead, and zinc. In addition, although there is not a screening level for sulfate, it is also evaluated as an indicator of mining-related impacts (such as acid rock drainage [ARD]).
- For groundwater: arsenic, lead, nitrate, sulfate, and total dissolved solids (TDS).
- For ambient air: arsenic.

Contaminant Sources and Impacts

Impacted areas have been characterized by media (that is, soil, sediment, surface water, groundwater, and ambient air). Source materials such as tailings are included in soil or sediment, depending on their location and degree of saturation. The following sections provide summaries of the distribution of primary COIs within each media examined in the RI. The discussion is focused on the primary COIs and indicator chemicals; more detail on these and other chemicals found at the Site are provided in the RI Report. Impacted areas are grouped into the following categories:

- Soil in Non-Residential Areas
- Soil in Residential Areas
- Sediment
- Surface Water
- Groundwater
- Ambient Air

The sources of contamination at the former mine and smelter properties are associated primarily with stockpiled mine and smelter waste created during a long history of operations. Sources include:

- Underground mining and the production of ore, waste rock, and waste transmitted by surface discharges and air dispersion at the former Iron King Mine property
- Ore processing, smelting, production of tailings and smelter waste, and air emissions from smelter stacks at the former Humboldt Smelter property
- Release of tailings and other waste materials to the environment at both properties

Releases and transport of contamination from these sources resulted from a number of processes, including operational discharges, impoundment failures, placement of mine and smelter waste in drainages or nearby properties, erosion during storm events, spills during transport along rail routes, smelter stack emissions, windblown particulates, and use of mine waste material as fill material and road base. Other transport mechanisms at work at this Site, and evaluated in this RI Report, include ARD discharges to groundwater or surface water, and metal leaching of soils, tailings, and sediments.

Transport of contaminants via surface water occurred through discharge to one of two intermittent surface water features that feed the Agua Fria River in the vicinity of the Site: Chaparral Gulch and Galena Gulch.

- Chaparral Gulch is an intermittent drainage that flows southeast through parts of both properties and intersects with the Agua Fria River on the southeast side of the former Humboldt Smelter property.
- Galena Gulch is an intermittent drainage that crosses the southwest corner of the former Iron King Mine property and flows south/southeast to intersect the Agua Fria River about 1 mile downstream of the Chaparral Gulch-Agua Fria River confluence.

Source areas and transport mechanisms are illustrated on Figure ES-6, which provides an oblique view of the Site, and Figure ES-7, which provides a cross section view from west to east.

Impacted and potentially impacted areas include: (1) the former Iron King Mine and Humboldt Smelter properties; (2) peripheral or undeveloped areas; (3) Galena Gulch; (4) Chaparral Gulch; (5) the Agua Fria River; and (6) non-residential and residential parcels within the Town of Dewey-Humboldt.

Soil in Non-Residential Areas

This section discusses the contaminant levels in non-residential areas, beginning with a description of sitewide contamination, and then a description of changes in contaminant levels starting from the location of maximum contamination at the former Iron King Mine property and moving downstream within the Chaparral Gulch. The section concludes with a discussion of the geochemical signatures for the former Iron King Mine and Humboldt Smelter source materials, and the volume of source materials.

Sitewide Contaminant Levels

The largest volume of source material (estimated to be 3,500,000 cubic yards [yd^3]) in a single source area is present in the MTP on the former Iron King Mine property. Other source areas at the former Iron King Mine property contain an additional estimated 165,500 yd^3. Source areas present at the former Humboldt Smelter property and within Chaparral Gulch contain an estimated 2,195,500 yd^3. These volumes will be re-estimated during the feasibility study (FS) to incorporate data collected throughout the four phases of the RI.

Figures ES-8 and ES-9 provide an overview of sitewide surface soil concentrations of arsenic and lead, respectively.

The average arsenic concentration for the 2,206 samples collected in the non-residential (NR) exposure areas equaled 338 mg/kg. Approximately 83 percent of the samples exceeded background for arsenic (112 mg/kg) and 34 percent exceeded the screening level (194 mg/kg). Of the 750 samples that exceeded the screening level, the average arsenic concentration equaled 1,102 mg/kg. Arsenic concentrations exceeded 1,000 mg/kg in 14 exposure areas, and exceeded 10,000 mg/kg in three exposure areas (NR11, NR12, and NR17).

The average lead concentration for the 2,206 samples collected in the non-residential exposure areas equaled 643 mg/kg. Approximately 73 percent of the samples exceeded background for lead (34.8 mg/kg) and 30 percent exceeded the screening level (194 mg/kg). Of the 652 samples that exceeded the screening level, the average lead concentration equaled 2,250 mg/kg. Lead concentrations exceeded 10,000 mg/kg in nine exposure areas, and exceeded 20,000 mg/kg in four exposure areas (NR8, NR11, NR16, and NR17).

Former Iron King Mine Property

The greatest concentrations of arsenic and lead were found in the area of, and adjacent to, the former Iron King Mine property. All of the samples from the MTP exceeded the screening level for arsenic (194 mg/kg) and lead (400 mg/kg). The average arsenic concentration for the 79 MTP samples equaled 3,974 mg/kg; the average lead concentration equaled 3,449 mg/kg. The maximum arsenic concentration of 13,000 mg/kg was detected at a depth of 4.5 feet in the lower portion of the MTP. The maximum lead concentration of 24,000 mg/kg was detected in a sample collected at a depth of 14.5 feet in the upper portion of the MTP.

Elevated arsenic and lead concentrations were also found in soil samples collected in exposure areas immediately adjacent to the MTP including the former Mineworks area (NR16), former Glory Hole and north of MTP (NR19), and south of former Iron King Mine property (NR14). Review of the historical aerial photographs demonstrated that these adjacent areas contained mine shafts, process impoundments, tailings ponds, and waste rock piles.

JT Septic Facility and MTP 1964 Blow Out Path

Sampling and testing within exposures areas downgradient from the former Iron King Mine property demonstrates that tailings from the MTP are present in the JT Septic Facility (NR4) and the MTP Blow Out Path (NR5). These areas both contain soils with elevated arsenic and lead. Tailings are visible in the yard at the corner of Third Street and Omega Drive, and within the drainage ditch on the south side of Third Street across from Richards Lane. Two subsurface samples at the small tailings pile across from Richards Lane had arsenic concentrations of 540 and 443 mg/kg, both well above background and screening levels (112 and 194 mg/kg) for arsenic. Lead concentrations greater than 10,000 mg/kg were found in surface samples located on the south side of Third Street near the center of the NR5 exposure area.

Middle Chaparral Gulch

Downstream from NR5, elevated arsenic and lead were found in surface and subsurface soils in the Middle Chaparral Gulch (NR6). The aerial photographs and soils data indicate that NR6 was impacted by tailings and impacted water from the former Iron King Mine operations that were transported under the Highway 69 culvert and through Upper Chaparral Gulch, and by tailings discharged through NR4 and NR5 during the MTP 1964 Blow Out. The Middle Chaparral Gulch consists of several active channels incised into alluvial channel fill. Tailings are present within the gulch along the banks of the middle and eastern edge of the channel, and outside the southern channel, likely through overbank deposition of the tailings and erosion of previously deposited tailings. Review of the surface and subsurface data shows that mining-impacted soil has been deposited intermittently with non-impacted material throughout the exposure area.

Tailings Floodplain

The Tailings Floodplain (NR8) is located downstream of Middle Chaparral Gulch (NR6), and extends from the southern boundary of the Smelter Tailings Swale (NR7) to below the Chaparral Gulch Dam (Figure ES-4).

The Tailings Floodplain has been impacted by discharges of tailings from the former Iron King Mine property, including the MTP 1964 Blow Out, and tailings associated with operations at the former Humboldt Smelter property. Similar to that observed in the Middle Chaparral Gulch, the deposits consist of an interbedded mixture of tailings and less-impacted material, likely conveyed from Chaparral Gulch upstream of Highway 69 during large storm events.

The Chaparral Gulch Dam impounds tailings and native alluvial deposits, which increases in thickness downstream approaching the dam, where the floodplain is more confined and the saturated thickness exceeds 20 feet. Little or no storage capacity remains behind the dam because of the accumulation of tailings and alluvium, which can now continue to migrate downstream to the Agua Fria River. Efflorescent salts are present on exposed tailings in the floodplain. These salts form by repeated cycles of wetting and drying, which concentrates metals in a highly mobile form. The dam restricts groundwater flow in the saturated sediment behind the dam. Seepage discharges from the toe of the dam throughout the year.

Surface samples with elevated arsenic concentrations are present across the width of the gulch at the upper third of the Tailings Floodplain (NR8). Within the lower half of NR8, most of the elevated arsenic concentrations in surface soils (greater than 400 mg/kg) are found on the western bank above the centerline of the gulch, indicating deposition of overbank impacted material during storm events.

For those samples that exceeded the screening level, the subsurface samples had an average arsenic concentration (816 mg/kg), almost double that of surface samples (484 mg/kg). Of the 33 samples that exceeded 1,000 mg/kg, 5 samples were obtained at the surface while the remainder (28) were subsurface. The maximum arsenic concentration (3,640 mg/kg) was recorded at a depth of 7.5 feet in the Tailings Floodplain just upstream from the Chaparral Gulch Dam. As observed with respect to the arsenic distribution, many more subsurface samples (greater than 2 feet below ground surface) had high concentrations of lead compared to subsurface samples. Of the 49 surface and subsurface samples with lead concentrations greater than 1,000 mg/kg, 39 samples were subsurface, while 10 were surface samples. The largest lead concentration (45,900 mg/kg) was recorded at a depth of 10 feet below ground surface in the Tailings Floodplain just upstream from the Chaparral Gulch Dam.

Former Pyrometallurgical Operations Area

The former Pyrometallurgical Operations area (NR11) encompasses the former Humboldt Smelter property where the majority of the smelting operations took place. Ore was received in rail shipments and offloaded at the northern portion of the area where the ore was processed to form copper concentrates. Ore concentrate was melted in furnaces, molten slag was separated from molten copper, and molten copper was then further refined to ingots in a series of converters. Tailings from the ore concentrators was discharged into impoundments located throughout the area, with most of the tailings placed behind berms on the Smelter Tailings Swale (NR7).

Samples collected within NR11 were classified as tailings, dross, ash pile, slag, Hickey Formation, and native soils. Elevated arsenic and lead concentrations were found primarily: (1) within the northern portion of NR11 in the area of the rail trestle, ore conveyors, and crushers; (2) in the upper middle portion of NR11 in the area of the former converters and smelters; and (3) at the perimeter to the northeast and west where tailings were placed. For all samples collected, the average concentrations of arsenic and lead equaled 709 and 1,409 mg/kg, respectively. Twenty-two percent of the samples exceeded the screening level for arsenic (194 mg/kg), while 53 percent of the samples exceeded the screening level for lead (400 mg/kg). The area is now covered with a thin layer of dross, a fine- to medium-grained material imported after closure and dismantling of the Humboldt Smelter plant for reprocessing to recover aluminum and zinc.

Slag deposits consist of black, brownish black, and bluish green glassy (amorphous) material. The slag appears to have been dumped as solidified blocks, portions that have been subsequently weathered to gravel or boulder-sized pieces. Other portions of the slag pile appear to have been placed while molten, forming sheets and flows, which later solidified. The slag deposits have formed a steep bluff overhanging the Agua Fria River. Slope failures have occurred, and the slag extends down to the edge of the Agua Fria River in places.

Smelter Tailings Swale

The Smelter Tailings Swale (NR7) was used to store tailings produced as a waste product from ore processing. Historical aerial photographs indicate the presence of several small dams and impoundments within the swale, all of which failed by 1940. The largest berm is visible across the bottom of the swale. Its failure has left a gully about 15 feet deep. Remnant tailings within the swale are up to 12 feet thick. The RI investigation (Lockheed Martin SERAS, 2015) estimated that more than 14,000 yd^3 of tailings remain on the slope. Only about 25 percent of the soil samples had arsenic concentrations greater than the screening level, and only two samples had arsenic concentrations greater than 325 mg/kg. Lead concentrations followed a similar pattern as that found for arsenic. Only 12 percent had lead concentrations greater than the screening level.

Smelter Plateau

The Smelter Plateau (NR12) is located south of the former Pyrometallurgical Operations area. This area was the site of the earliest mining operations, prior to construction of the Humboldt Smelter. The Chaparral Gulch Shaft mine was located in the southeastern portion of the Smelter Plateau providing ore to the Agua Fria Ore Mill and Smelter in the 1870s and 1880s. Tailings from these operations were deposited in a tailings pile located at the downstream end of the Lower Chaparral Gulch (NR9) and at the Agua Fria Tailings Pile (NR10) located adjacent to the Agua Fria River. Both of these tailings piles contain elevated levels of arsenic and lead.

Residential housing, known as Nob Hill, was built in the early 1900s for smelter managers. Remains of tennis courts and home foundations are still present in the area. Piles of dross are exposed on the plateau, and a small slag pile is located along the eastern edge of the plateau, upslope from the Agua Fria River. A tailings pile is located in the former housing area.

Geochemical Signatures for the Former Iron King Mine and Humboldt Smelter Properties

Statistical analysis of key metals (lead, copper, and zinc) and their ratios (lead to copper [Pb:Cu] and zinc to copper [Zn:Cu]) were used to evaluate the fate and transport of tailings from the former Iron King Mine and Humboldt Smelter properties. These metals and ratios are diagnostic of materials being from either the Iron King Mine or the Humboldt Smelter. The objective of the analysis was to assess whether Iron King Mine tailings or Humboldt Smelter tailings sediment mixtures have accumulated in the former Humboldt Smelter property Tailings Floodplain upstream of the Chaparral Gulch Dam (Figure ES-4).

Volume of Source Materials

Source material is defined as media that include or contain hazardous substances, pollutants, or contaminants that act as a reservoir for migration to other media or for direct exposure (EPA, 1991b). Source material volume estimates were developed as part of the Initial RI (EA, 2010) and the Data Gap RI (Lockheed Martin SERAS, 2015). A revised estimate of the MTP volume was also performed as part of the current RI Report preparation. These volumes will be re-estimated during the FS to incorporate data collected throughout the four phases of the RI. Volumes will be subdivided by exposure area to the extent feasible, and overburden (material present on top of source materials) will also be estimated.

Soil in Residential Areas

In addition to (1) the potential transport of contamination from the former mine/smelter property source areas to residential areas via windblown dust, tailings, dross, and impacted soil; (2) particulate stack emissions; (3) surface water transport and deposition along Chaparral Gulch; (4) spills and material releases along historical rail routes; (5) use of waste material as fill at residential properties; and (6) redistribution of contamination through development, there are numerous non-site-related sources that have impacted concentrations. Naturally occurring arsenic (and other metals) is associated with silicic volcanic materials such as rhyolite, which are widely present within the region. Fill has been imported from quarries with naturally elevated concentrations of arsenic, and cut-and-fill activities have occurred in areas of naturally elevated concentrations of arsenic east of the Agua Fria River. Non-site-related sources of lead include use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires.

The result of site-related and non-site-related sources of metals, in addition to the redistribution of contamination during development, has resulted in a complex patchwork distribution of metals in residential areas. For this reason, multiple phases of sampling were performed in residential areas, with the most extensive sampling efforts occurring between 2008 and 2012, and between 2013 and 2014. In total, approximately 6,300 soil samples were collected from residential properties within the APSI.

For RYSR areas, sampling was performed and analytical results were evaluated on a yard-by-yard basis. For RSAR areas, properties located near the boundary of the APSI, and less likely to have been impacted by the Site, were divided into manageable screening subareas labeled A through J. Each screening area contained many contiguous properties. The investigation plan included the contingency that if the overall site-related risk, or even high individual values, emerged from the screening investigation, then the screening area would be converted to an RYSR area and all properties in the area would be sampled. If the area characterized as a whole posed only low residential risks and had no significantly elevated levels, then yard-by-yard sampling would be unnecessary. Each screening area was sampled and a screening evaluation was done. EPA took care to ensure that no single property received too many samples, and that samples were reasonably and representatively spread across the entire area.

For the RYSR exposure areas, the largest concentrations of arsenic and lead in soil samples were detected in areas surrounding the former Humboldt Smelter property, and areas that overlap or are adjacent to the Upper or Middle Chaparral Gulch. In general, where arsenic or lead concentrations are elevated in shallow soil samples collected off the mine and smelter properties, their concentrations are lower in the collocated deeper samples, which is consistent with aerial deposition of windblown dusts and smelter emissions. Exceptions include areas were deeper soil contamination is known to occur, including along the former Smelter Spur, the Tailings Floodplain of Chaparral Gulch, and the confluence of the MTP Blow Out Path and Upper Chaparral Gulch into Middle Chaparral Gulch. Anthropogenic factors, such as grading for property development and importing fill for landscaping, may have altered the distribution of arsenic and lead in the downwind areas.

For RSAR exposure areas, although some arsenic or lead concentrations exceed background or screening levels locally (that is, in discrete samples), the calculated exposure point concentrations (across the areas) do not exceed screening levels, with the exception of a hot spot area at a stormwater diversion berm known to be made using imported mine tailings.

Sediment

Primary COIs with the lowest concentrations were detected in upstream reaches of the Agua Fria River, Chaparral Gulch, and Galena Gulch. The maximum concentrations of arsenic, lead, mercury, and zinc were detected in former Iron King Mine property source areas. The highest concentrations of copper were detected in, and adjacent to, former Humboldt Smelter property source areas. Concentrations of the primary COIs exceeded screening levels in most of the samples collected from the former Iron King Mine and Humboldt Smelter property source areas and downstream portions of Galena Gulch and Chaparral Gulch. Concentrations also exceeded screening levels in the Agua Fria River, primarily in locations near former Humboldt Smelter property source areas and the confluence with Chaparral Gulch.

Surface Water

Concentrations of the primary COIs exceeded screening levels in much of Chaparral Gulch and Galena Gulch, and were higher in downstream reaches of these streams due to site-related impacts. The highest concentrations of COIs were detected in surface water on top of, and at the base of, the MTP; in Chaparral Gulch downstream of Iron King Mine; and in the area of the Tailings Floodplain and Chaparral Gulch Dam. Site-related contamination in the Agua Fria River was limited to locations near the Humboldt Smelter slag pile and at, and immediately downstream of, the confluence with Chaparral Gulch.

Groundwater

During the course of the investigations described in this RI Report, EPA installed 26 monitoring wells screened in the alluvium (and tailings), Hickey Formation, and Precambrian bedrock (these strata are illustrated on Figure ES-7). In addition, numerous domestic supply wells in the vicinity of the Site were sampled during pre-NPL investigations and the initial phase of the RI. Review of the groundwater data from monitoring wells and domestic wells indicates the following:

- Sulfate concentrations in the deeper bedrock monitoring wells beneath and near the former Iron King Mine and Humboldt Smelter properties are not elevated and the water chemistry signature is distinctly different, indicating a lack of hydraulic communication between the shallow groundwater and the deeper fractured basement rocks.
- Elevated sulfate concentrations demarcate groundwater impacted by ARD generation. The area of impact is limited to the shallow groundwater zones beneath and between the mine and smelter properties and along Chaparral Gulch. The groundwater pH is slightly lower in areas where elevated sulfate concentrations occur, but repeatable pH values below 6 were not observed, indicating that residual neutralizing capacity in waste materials and local soils and groundwater matrix minerals are buffering the ARD acidity.
- ARD impacts from metals are more localized than sulfate. Arsenic, lead, and TDS locally exceed screening levels in shallow groundwater underlying and immediately downgradient of the MTP and in the saturated tailings-impacted alluvium impounded upstream of the Chaparral Gulch Dam.
- Groundwater in the vicinity of the Humboldt Smelter exceeds screening levels for chloride, nitrate, and TDS. These exceedances may be associated with releases of wastewater from dross processing, leaching of exposed dross, or a combination of these processes. The TDS, chloride, and nitrate impacts associated with the Humboldt Smelter site may extend off-property to nearby domestic wells.
- Regionally, groundwater impacts, including elevated arsenic concentrations in public and private wells and EPA bedrock monitoring wells, is associated with natural mineral sources in the area, and not mining sources. The majority of private and public supply wells in Humboldt Proper near the Site have arsenic concentrations below the MCL (0.01 milligram per liter [mg/L]), and where exceedances do occur, the concentrations are less than 0.03 mg/L. In contrast, many of the private supply wells northeast of the Site (to the east side of the Agua Fria River) and private supply wells sampled to the south of the former smelter property have concentrations exceeding MCLs for arsenic, and in some cases, concentrations exceed 0.1 mg/L. These are areas where naturally elevated concentrations of arsenic and other metals have been detected in soil and rock outcrops. These areas would not be subject to groundwater transport of site-related contamination. EPA, the Agency for Toxic Substances and Disease Registry, ADEQ, Arizona Department of Health Services, and other state and local health agencies are encouraging residents to test private well water for arsenic and lead, and if concentrations are above drinking water standards, to install a water treatment system (Arizona Department of Health Services, 2016).

- Nitrate and TDS concentrations exceed primary and secondary MCLs, respectively, in supply wells in the Dewey-Humboldt area. However, aside from the area immediately north of the former Humboldt Smelter property, these exceedances are suspected to be associated with older septic systems and past agricultural activities.

Ambient Air

Of the primary COIs identified for ambient air, arsenic exceeds the screening level for more samples than the other COIs; however, the test results demonstrate that unacceptable residential health risks were not identified for any of the ambient air monitoring stations near current residential areas.

Risks to Human Health and the Environment

EPA uses risk assessments to characterize the nature and magnitude of health risks to humans (residents, workers, and recreational visitors) and ecological receptors (birds, fish, and wildlife) from chemical contaminants and other stressors that may be present in the environment. Chemical concentrations are measured in various media (soil, ambient air, sediment, and surface water) to characterize the nature and extent of chemical contamination in the environment, and evaluate how the contaminants may behave in the environment.

The risk assessments are used to evaluate the frequency and magnitude of human and ecological exposures that may occur because of contact with the contaminated media, both now and in the future. This evaluation of exposure is then combined with information on the inherent toxicity of the chemical (that is, the expected response to a given level of exposure) to predict the probability, nature, and magnitude of the adverse health effects that may occur. EPA uses the information from the risk assessments to determine whether site cancer or noncancer risks are great enough to potentially cause health problems for people at or near the Site.

Human Health Risk Assessment

For evaluation of human health risks, the Site was divided into separate soil exposure areas based on current or future land use, former operations, waste types and source materials, and property boundaries. These are the same exposure area groupings used to define the nature and extent of contamination. Exposure areas defined for soil were given one of four designations based on current or potential future land use.

Figures ES-8 and ES-9 illustrate the locations of the evaluated exposure areas, which include non-residential, non-residential/possible future residential, RYSR, and RSAR land uses.

The human health risk assessment (HHRA) was performed to evaluate the frequency and magnitude of human exposures that may occur because of contact with contaminated media, both now and in the future, and identified contaminants of potential concern (COPCs) that are potentially accessible for human exposures. The COPCs were evaluated to identify and eliminate from further consideration those contaminants that are unlikely to contribute substantially to overall risks at the Site. COPCs are different from COIs in that they are not just indicators of contamination associated with site sources, but are representative of those site-related contaminants that present a risk.

Risks were estimated for the most plausible pathways of human exposure based on available sampling data, and a current understanding of reasonably anticipated land uses and beneficial water uses at the Site. The exposure scenarios evaluated include the following:

- Current or future residents
- Current or future occupational workers
- Intermittent recreational visitors (for example, hikers)

Groundwater data were not evaluated as part of the HHRA because: (1) site-related impacts to groundwater appear to be confined to the former Iron King Mine and Humboldt Smelter properties and the area between them; and (2) regional groundwater quality includes naturally elevated arsenic, and local domestic water quality may be affected by septic systems and other non-mine-related activities.

Consistent with EPA guidance, potential risks and hazards were estimated in the HHRA by computing incremental site risks for soil. Incremental risk is defined as the portion of site risk in excess of that resulting from normal regional background/ambient concentrations of metals, and presumably attributable to site-related releases.

A site-specific bioavailability study was conducted to provide a better understanding of the oral bioavailability of arsenic in soil that may have been affected by site-related releases. The exposure estimates for arsenic in soil were adjusted to account for the site-specific bioavailability identified for arsenic, to provide for more realistic estimates of risk.

In addition, for evaluation of noncancer effects, both combined child/adult and child-only scenarios were considered in the HHRA. The child-only scenario is a more health-conservative evaluation that is performed as a site-specific uncertainty analysis, and is included to provide EPA with added input for determining borderline decisions for remediating specific properties at the Site.

The HHRA found that more than 92 percent of yards within the APSI do not have levels of arsenic or lead that pose an unacceptable health risk. Incremental human health risks that exceeded acceptable thresholds were identified for exposure areas within the former mine and smelter properties, as well as some adjacent areas. No unacceptable human health risks were identified for recreational surface water and sediment exposures within the Agua Fria River. In terms of ambient air, concentrations of arsenic in ambient air sampled at Humboldt Proper and on the former Humboldt Smelter property were similar to background concentrations, and no residential health risks exceeding the EPA risk thresholds were identified for any of the ambient air monitoring stations near current residential areas.

Ecological Risk Assessment

The ecological risk assessment (ERA) was performed to provide an analysis of the potential for adverse effects on ecological resources associated with the Site. The ERA identifies and characterizes the toxicity of contaminants of potential ecological concern, the potential exposure pathways, the potential ecological receptors, and the likelihood of adverse ecological effects under current and reasonably anticipated future land and water use conditions. The ERA followed the tiered approach recommended by EPA in that both a screening-level ERA (Tier 1) and a baseline ERA (Tier 2) were performed.

An ecological conceptual exposure model was developed for the Site to focus the ERA on the most plausible ecological receptors and pathways. Potentially complete ecological exposure pathways at the Site include the following:

- Potential exposure of soil invertebrates and terrestrial plants to site-related constituents present in soil
- Potential exposure of terrestrial wildlife (birds and mammals) through ingestion of site-related constituents in soil, terrestrial forage, and/or prey items
- Potential exposure of aquatic and benthic resources within the Agua Fria River (aquatic plants, benthic and water column invertebrates, and fish) to site-related constituents present in sediment or surface water
- Potential exposure of semi-aquatic wildlife (birds and mammals) through ingestion of site-related constituents in sediment, aquatic forage/prey, and surface water

Because the Site covers a large geographic area, it was divided into numerous ecological exposure areas, as shown on Figure ES-10. Those areas surrounding the residential areas and along the Agua Fria River were identified as the primary points of exposure for ecological receptors. Potential ecological exposures were evaluated using representative endpoint species from the functional feeding guilds that may have potentially complete exposure pathways for terrestrial and semi-aquatic/aquatic exposures. In all, there were 33 terrestrial exposure areas evaluated for 10 representative species, 3 sediment exposure areas evaluated for 6 representative species, and 3 surface water exposure areas evaluated for 5 representative species.

Consistent with EPA guidance, potential ecological risks were estimated by computing incremental site risks for soil. Incremental risk is defined as the portion of the site risk in excess of that resulting from normal regional background/ambient concentrations of metals, and presumably attributable to site-related releases.

The ERA indicated that there is a potential for adverse risk to ecological receptors from selected metals detected in soil, sediment, and surface water at the Site. The ERA identified 15 of the 33 terrestrial exposure areas evaluated (see Figure ES-10) as having a limited, moderate, or high potential for adverse effects. The areas with a high potential for adverse effects were limited to source areas on the former mine and smelter properties (including the MTP, former Mineworks area, North American Industries, Inc. (NAI) Operations area, former Pyrometallurgical Operations area, Smelter Plateau, and Agua Fria Tailings Pile). The areas with low to moderate potential for adverse effects were located on or immediately adjacent to the properties and generally coincided with exposure areas where human health risk estimates also exceeded risk thresholds. The ERA also identified potential risk from exposure to surface water and sediment in the Agua Fria River in areas impacted by Humboldt Smelter source areas, the Agua Fria Tailings Pile, and discharges from Chaparral Gulch. These areas and metals are recommended for risk management consideration, and the evaluation of actions to address the associated ecological exposure pathways in the forthcoming FS for the Site.

Key Findings and Path Forward

The evaluations documented in this RI Report have resulted in a current understanding of the physical characteristics of the Site, the nature and extent of associated contamination, how and why the contamination was distributed and may continue to migrate if not addressed (fate and transport), and potential human health and ecological risks associated with the remaining contamination.

The Site has been sufficiently characterized and the areas of contamination have been adequately identified, investigated, and assessed. Preliminary calculations of the volume, depth, and areal extent of source areas have been prepared. EPA will take these findings and the extensive dataset compiled in this RI Report and screen, develop, and evaluate alternatives for remediation of contamination in an FS report.

As an illustration of the nature and extent of contamination documented through the four phases of this RI, Figure ES-8 shows the surface soil sample locations and range of concentrations of primary COI and COPC arsenic, from not detected to the highest detection of 20,200 mg/kg. Figure ES-9 shows the surface soil sample locations and range of concentrations of primary COI and COPC lead, from not detected to the highest detection of 65,700 mg/kg.

As work proceeds on the FS, primary findings for the residential areas include the following:

- More than 92 percent of the yards within the APSI do not have levels or arsenic or lead that pose an unacceptable health risk.
- Hot spots resulting from a combination of site-related and non-site-related sources of arsenic and lead are resulting in risks above EPA risk management thresholds in select yards. Incremental human

health risks exceeding risk thresholds (excess lifetime cancer risk is greater than 10^{-4}; hazard index is greater than 1, and/or lead is greater than 400 mg/kg) for residential soil exposures were identified for 34 RYSR yards. The impacted yards should be evaluated in the FS. Many of these yards are located north of the former Humboldt Smelter property in Humboldt Proper, along the historic Smelter Spur, and along areas of tailings deposition in Chaparral Gulch.

- Incremental human health risks exceeding risk thresholds for residential soil exposures were also identified for the stormwater diversion berm identified as a hot spot, and for one exposure area that may have future residential land uses.
- Remediation or institutional controls are required to prevent future exposure to sources areas resulting from change in land use.
- At the Humboldt Elementary School, soil metal concentrations were below screening levels and no unacceptable risks were identified in soil or ambient air.

As work proceeds on the FS, consideration must also be given to the potential for additional migration of contaminants from identified sources.

Primary considerations at the former Iron King Mine property include the following:

- Potential for additional slope failures at the MTP and associated migration of contaminated tailings
- Continued erosion of tailings, waste rock, and contaminated soils to Chaparral Gulch or Galena Gulch
- Potential for an increase in the generation of ARD and subsequent migration of sulfate, metals, and acid from the MTP to groundwater and surface water
- Potential for human and ecological contact with tailings, waste rock, and contaminated soil in former Iron King Mine source areas (MTP, former Mineworks area, and NAI Operations area) and areas north and south of the MTP
- Potential for dust generation and aerial suspension of tailings and fine-grained contaminated soils at the mine property during high-wind events (It should be noted that no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas.)

Primary considerations at the former Humboldt Smelter property, Chaparral Gulch, and the Agua Fria River include the following:

- Continued erosion of tailings from the Smelter Tailings Swale to the Tailings Floodplain and Lower Chaparral Gulch
- Potential for large-scale erosion of tailings and contaminated soil from Chaparral Gulch and the Tailings Floodplain to lower reaches of Chaparral Gulch and the Agua Fria River
- Potential failure of the Chaparral Gulch Dam
- Continued erosion of waste piles and contaminated soil to the Agua Fria River
- Potential for human and ecological contact with tailings, dross, slag, and contaminated soil and sediment within Chaparral Gulch depositional areas and Humboldt Smelter source areas
- Potential for ecological health risk from exposure to surface water and sediment in the Agua Fria River that is currently impacted by Humboldt Smelter source areas, the Agua Fria Tailings Pile, and discharges from Chaparral Gulch
- Potential for an increase in the generation of ARD and subsequent migration of sulfate, metals, and acid from the Tailings Floodplain to groundwater and surface water

- Potential for dust generation and aerial suspension of dross, tailings, and fine-grained contaminated soil at the smelter property during high-wind events (It should be noted that no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas.)

EPA will incorporate these RI Report findings and considerations for potential future migration into the FS for this Site. In the FS, EPA will identify an appropriate range of waste management options that would provide for protection of human health and the environment. The source volumes (and overburden volumes) will be refined to provide the best data for decision making, and potential remediation technologies will be considered and screened. EPA will develop remedial action objectives for the Site, and a range of remedial alternatives that will meet those remedial action objectives. Each remedial alternative will be subject to a detailed analysis and comparison.

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[1] Note: Works cited in the Executive Summary are also included in the main RI Report. Publications that include a sequential notation in the date (a, b, c following the year) are intended to match the notations in the main report.

Notes:

The boundaries of the former Iron King Mine and former Humboldt Smelter represent property boundaries and do not directly correspond to the area of historical operations or impacts.
Image Source: USDA, 2015.

Figure ES-1
Iron King Mine, Humboldt Smelter, and Surrounding Region
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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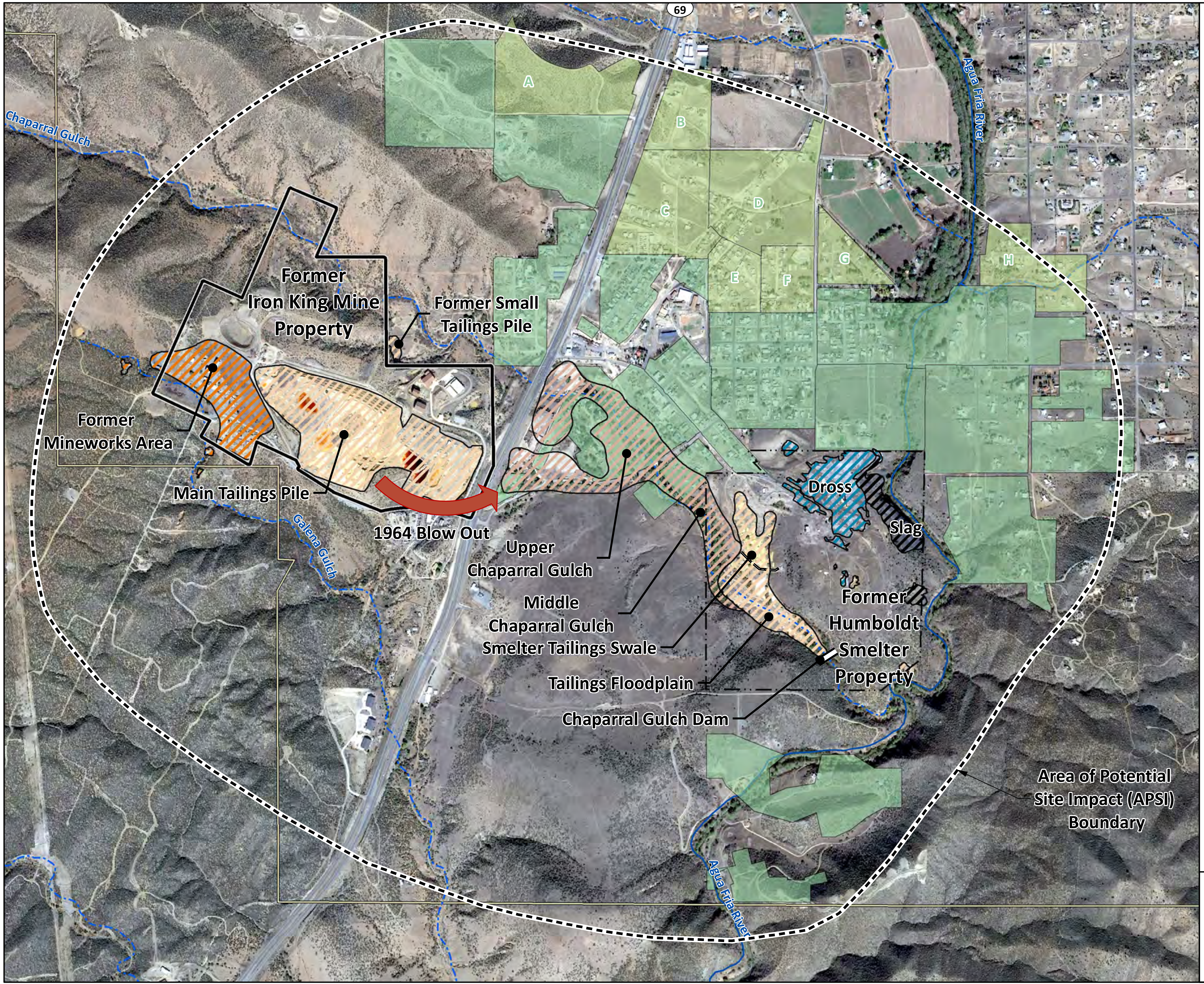
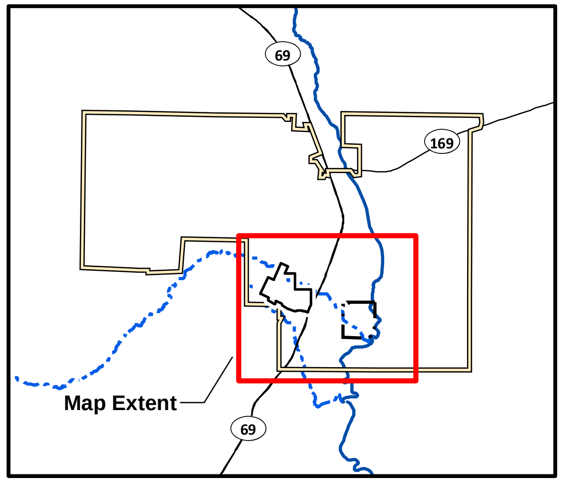




LEGEND

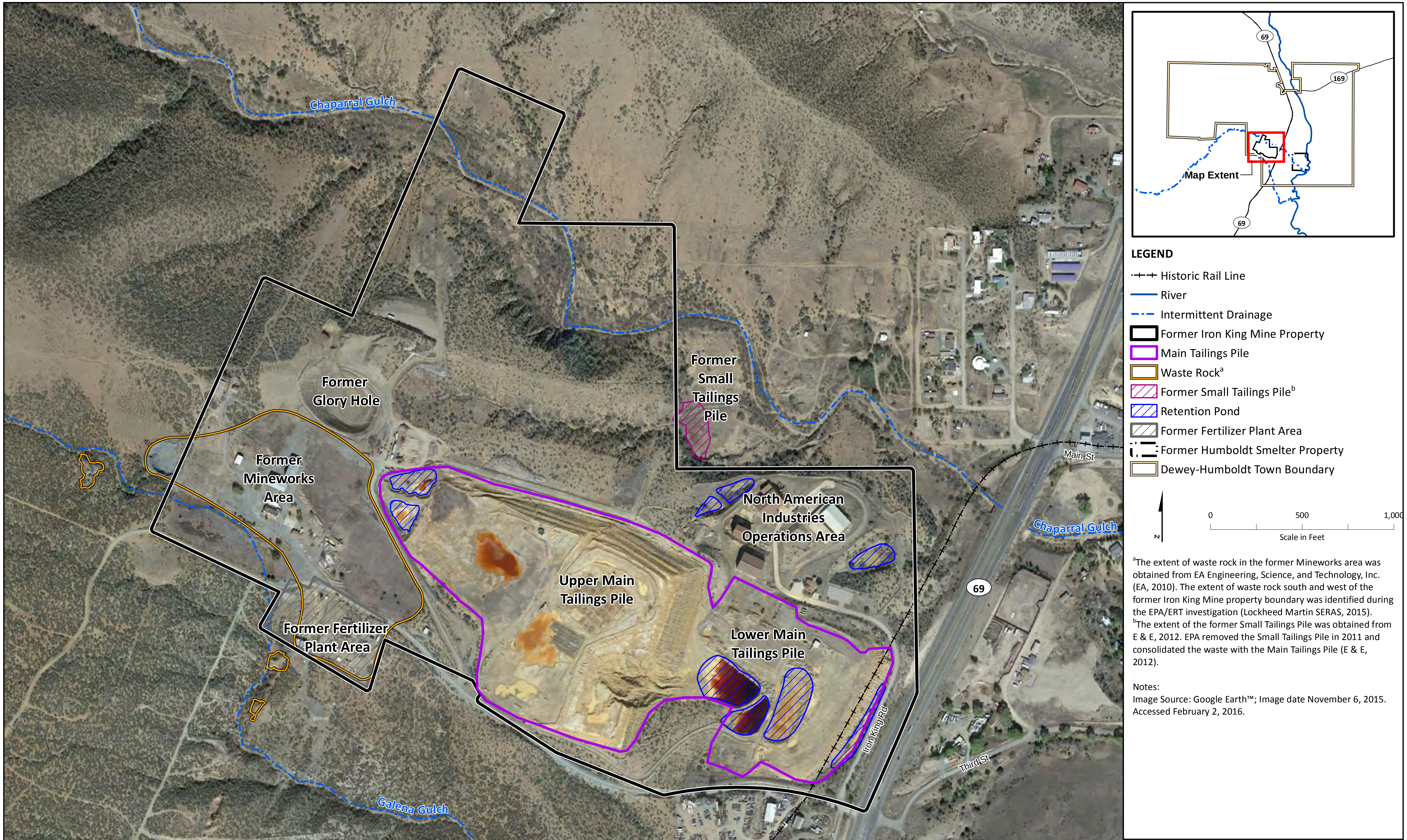
- River
- Intermittent Drainage
- 🟩 Screening Area Sampling
- 🟩 Yard-by-Yard Sampling
- ▨ Waste Rock
- ▨ Tailings
- ▨ Upper and Middle Chaparral Gulch Areas
- ▨ Slag Pile
- ▨ Dross Area
- Area of Potential Site Impact (APSI)
- Former Iron King Mine Property
- Former Humboldt Smelter Property
- Dewey-Humboldt Town Boundary

Notes:
EPA removed the Small Tailings Pile in 2011 and consolidated the waste with the Main Tailings Pile (E & E, 2012).
Image Source: Google Earth™; Image date November 6, 2015. Accessed April 6, 2016.

N

0 1,200 2,400
Scale in Feet

Figure ES-2
Sources of Contamination and Residential Sampling Areas
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona



[a] The extent of waste rock in the former Mineworks area was obtained from EA Engineering, Science, and Technology, Inc. (EA, 2010). The extent of waste rock south and west of the former Iron King Mine property boundary was identified during the EPA/ERT investigation (Lockheed Martin SERAS, 2015).

[b] The extent of the former Small Tailings Pile was obtained from E & E, 2012. EPA removed the Small Tailings Pile in 2011 and consolidated the waste with the Main Tailings Pile (E & E, 2012).

Notes:
Image Source: Google Earth™; Image date November 6, 2015. Accessed February 2, 2016.

Figure ES-3
Former Iron King Mine Property – Features
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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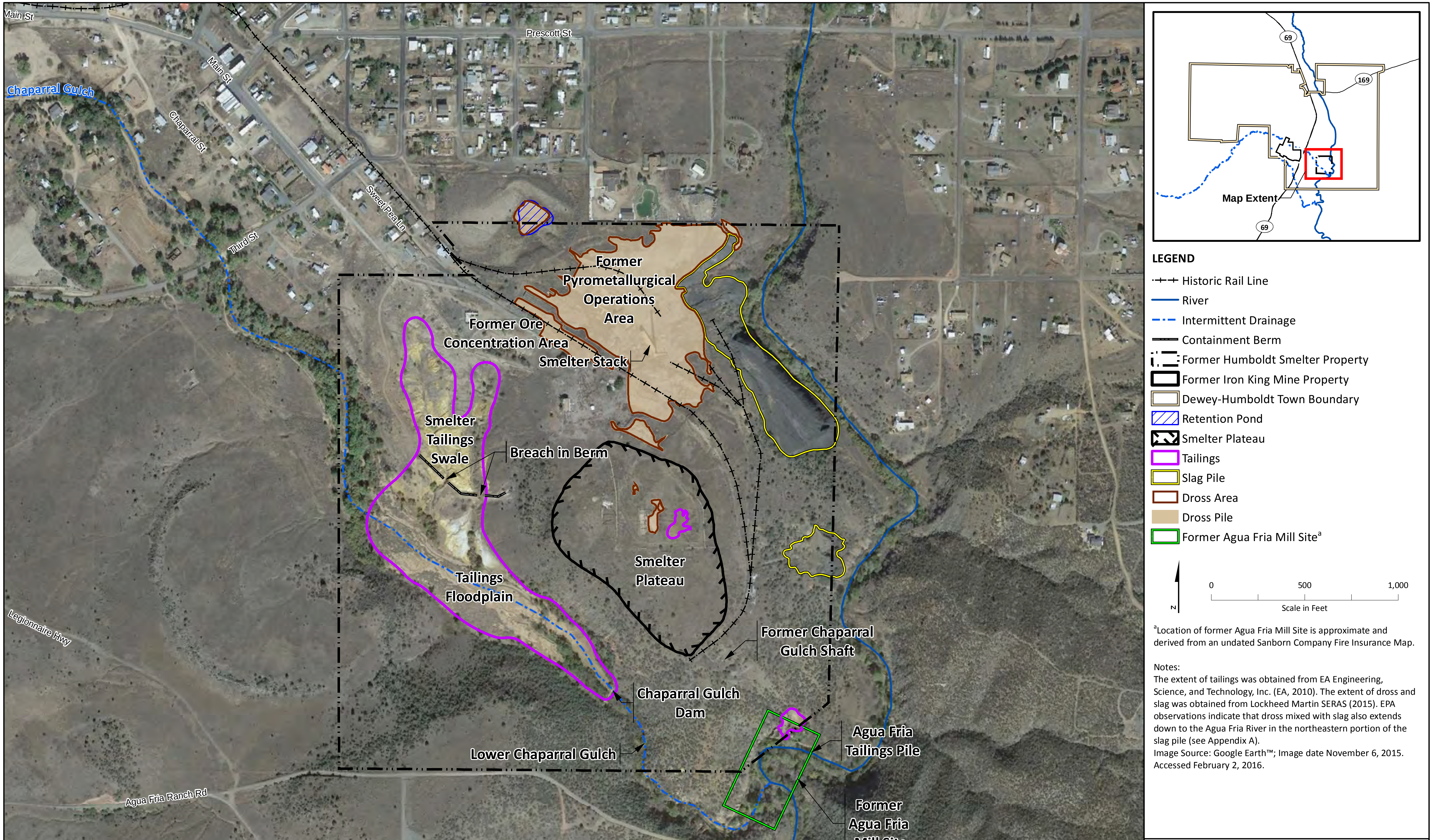

[a]Location of former Agua Fria Mill Site is approximate and derived from an undated Sanborn Company Fire Insurance Map.

Notes:
The extent of tailings was obtained from EA Engineering, Science, and Technology, Inc. (EA, 2010). The extent of dross and slag was obtained from Lockheed Martin SERAS (2015). EPA observations indicate that dross mixed with slag also extends down to the Agua Fria River in the northeastern portion of the slag pile (see Appendix A).
Image Source: Google Earth™; Image date November 6, 2015. Accessed February 2, 2016.

Figure ES-4
Former Humboldt Smelter Property – Features
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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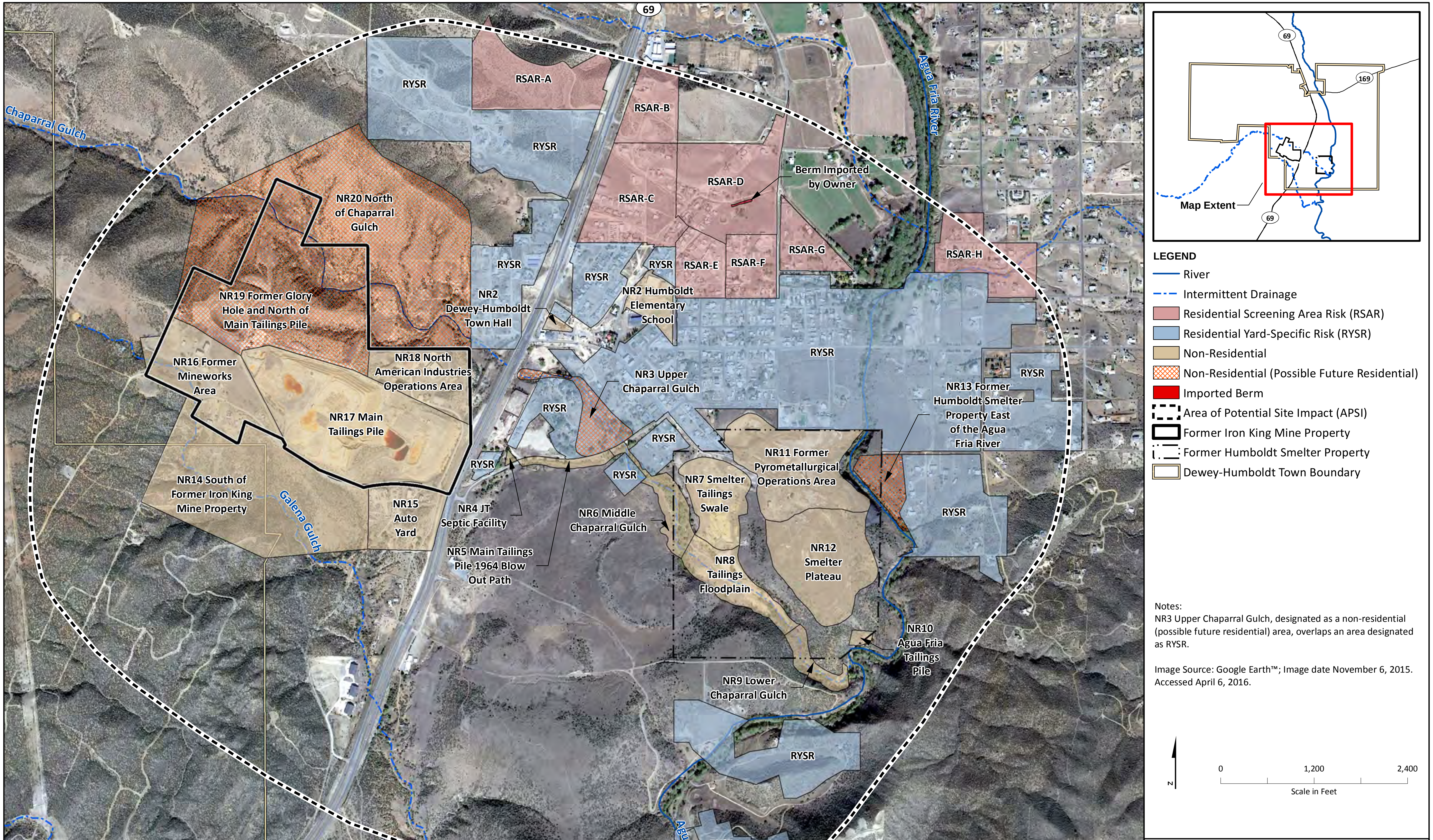

Notes:
NR3 Upper Chaparral Gulch, designated as a non-residential (possible future residential) area, overlaps an area designated as RYSR.

Image Source: Google Earth™; Image date November 6, 2015. Accessed April 6, 2016.

Figure ES-5
Exposure Areas
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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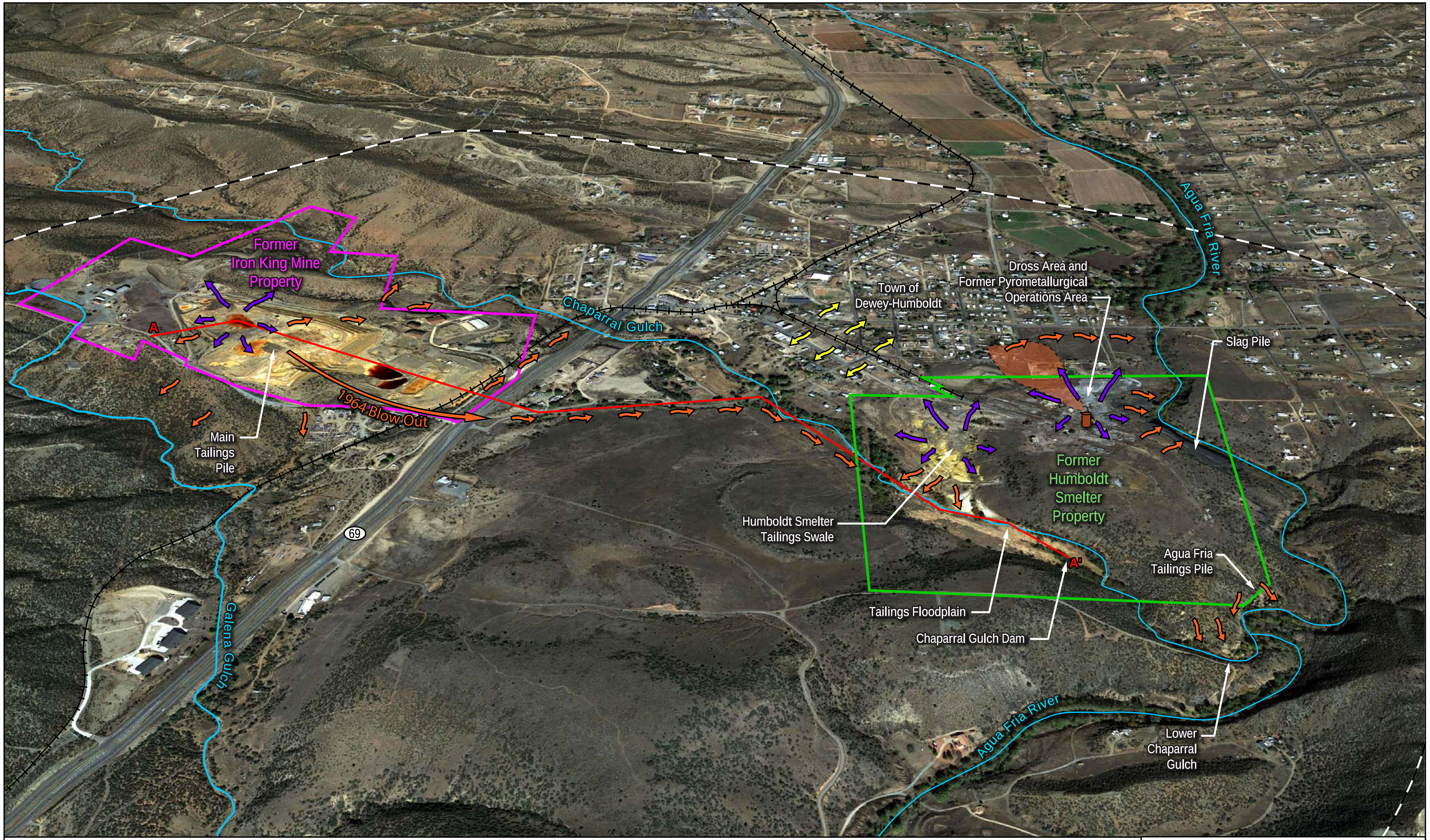


Note:
Transport mechanisms not depicted on this diagram or the associated cross section include placement or dumping of waste or use of tailings, waste rock, or contaminated soil as construction fill or road base in surrounding areas.

Figure ES-6
Contaminant Transport Mechanisms
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

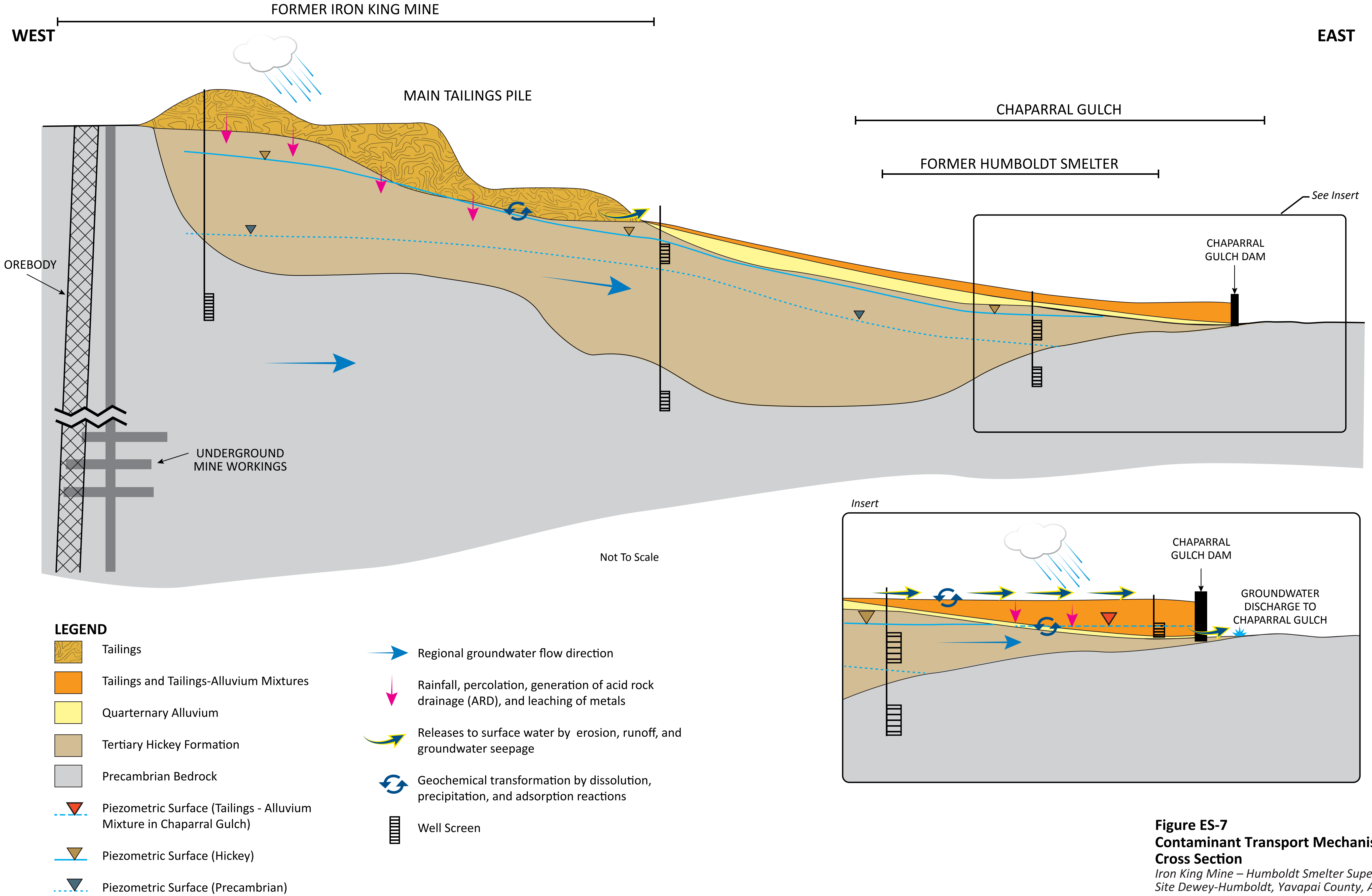
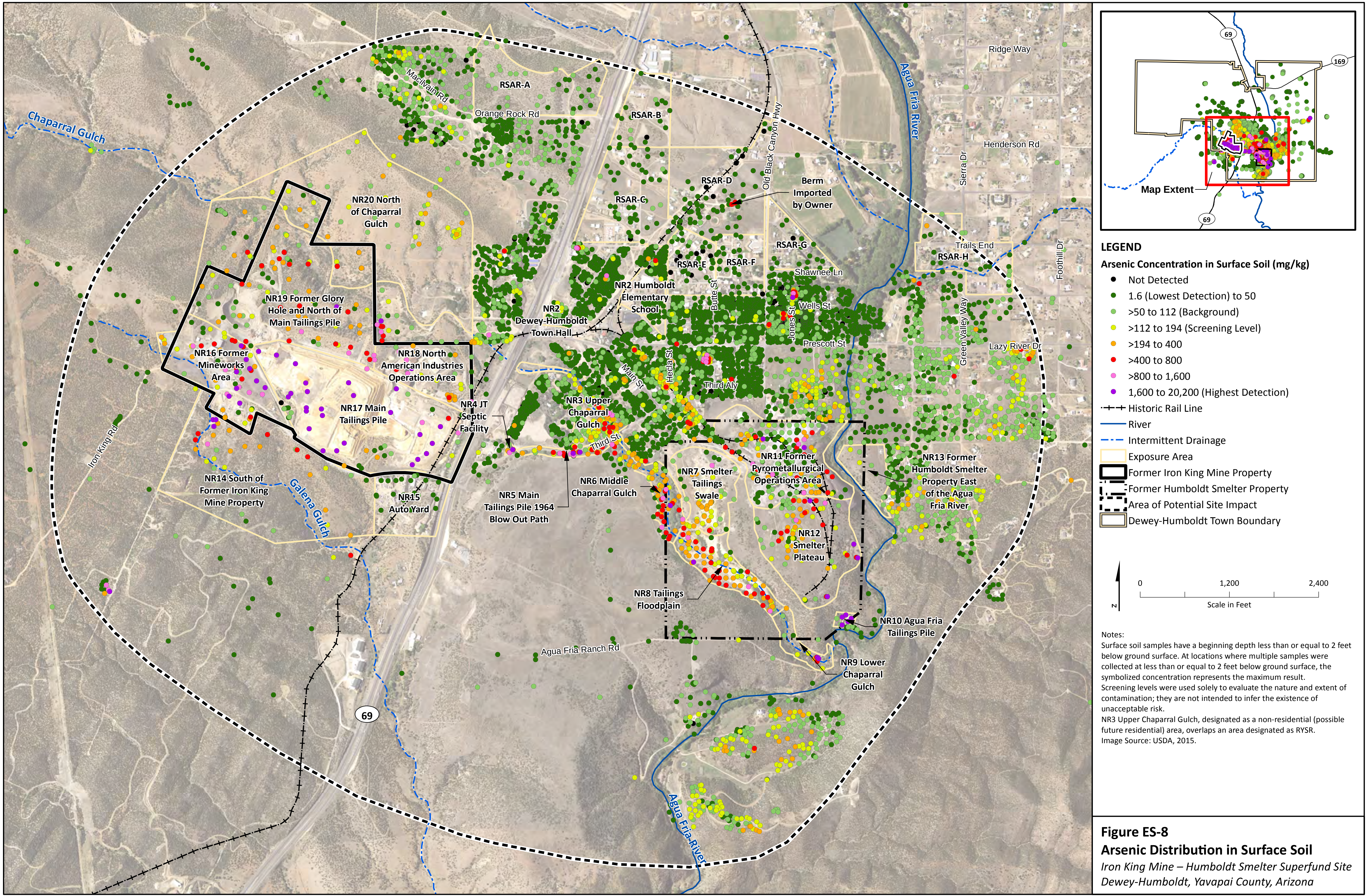


Figure ES-7
Contaminant Transport Mechanisms – Cross Section
Iron King Mine – Humboldt Smelter Superfund Site Dewey-Humboldt, Yavapai County, Arizona



Notes:
Surface soil samples have a beginning depth less than or equal to 2 feet below ground surface. At locations where multiple samples were collected at less than or equal to 2 feet below ground surface, the symbolized concentration represents the maximum result.
Screening levels were used solely to evaluate the nature and extent of contamination; they are not intended to infer the existence of unacceptable risk.
NR3 Upper Chaparral Gulch, designated as a non-residential (possible future residential) area, overlaps an area designated as RYSR.
Image Source: USDA, 2015.

Figure ES-8
Arsenic Distribution in Surface Soil
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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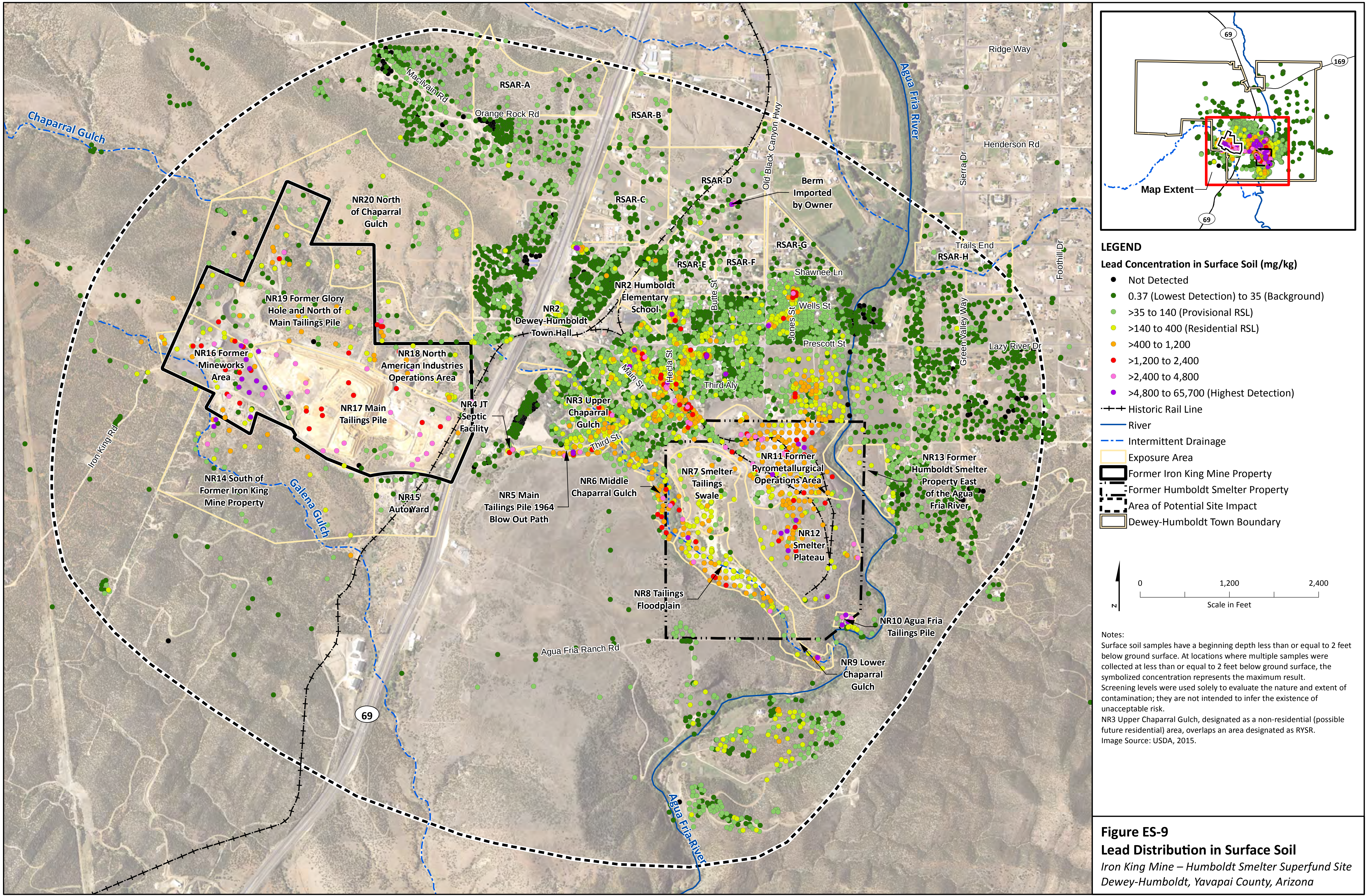

Notes:
Surface soil samples have a beginning depth less than or equal to 2 feet below ground surface. At locations where multiple samples were collected at less than or equal to 2 feet below ground surface, the symbolized concentration represents the maximum result.
Screening levels were used solely to evaluate the nature and extent of contamination; they are not intended to infer the existence of unacceptable risk.
NR3 Upper Chaparral Gulch, designated as a non-residential (possible future residential) area, overlaps an area designated as RYSR.
Image Source: USDA, 2015.

Figure ES-9
Lead Distribution in Surface Soil
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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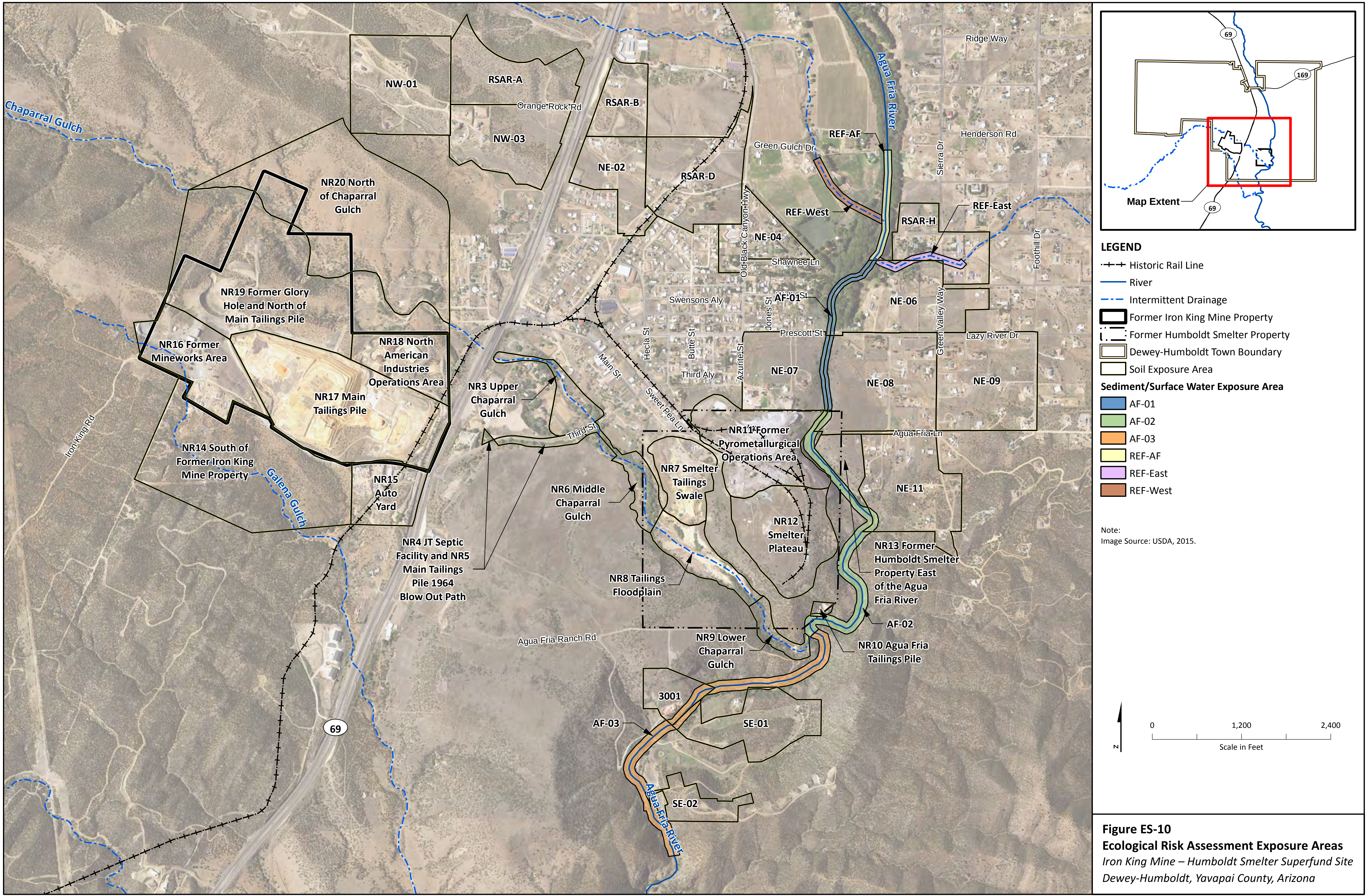

Figure ES-10
Ecological Risk Assessment Exposure Areas
Iron King Mine – Humboldt Smelter Superfund Site
Dewey-Humboldt, Yavapai County, Arizona

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Acronyms and Abbreviations

°F	degrees Fahrenheit
µg/dL	micrograms per deciliter
µg/L	micrograms per liter
$\mu g/m^3$	microgram per cubic meter
2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
2D	2-dimensional
3D	3-dimensional
ABA	acid-base accounting
ACCLPP	Advisory Committee on Childhood Lead Poisoning Prevention
ACS	Archaeological Consulting Services, Ltd
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
ALM	Adult Lead Model
AMA	Active Management Area
AP	acid-generating potential
APN	Assessor’s Parcel Number
APP	Aquifer Protection Permit
APSI	area of potential site impact
Aqua Tec	Aqua Tec, LLC
ARD	acid rock drainage
ASTM	ASTM International (formerly American Society for Testing and Materials)
AUF	area use factor
B[a]P	benzo[a]pyrene
BAF	bioaccumulation factor
BERA	baseline ecological risk assessment
bgs	below ground surface
BKG	background (sampling) location
BMP	best management practice
bss	below sediment surface
BTV	background threshold value
$CaCO_3$	calcium carbonate
CASC	Consolidated Arizona Smelting Company
CCME	Canadian Council of Ministers of the Environment

CDC	Center for Disease Control
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
cfs	cubic feet per second
Cgl	conglomerate
CH2M	CH2M HILL, Inc.
CLP	Contract Laboratory Program
cm	centimeter(s)
cm^2	square centimeter(s)
cm/sec	centimeters per second
COC	chemical of concern
COEC	chemical of ecological concern
COI	chemical of interest
COPC	chemical of potential concern
COPEC	chemical of potential ecological concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CPT	cone penetrometer testing
CSM	conceptual site model
E & E	Ecology and Environment, Inc.
EA	EA Engineering, Science, and Technology, Inc.
EcoSSL	ecological soil screening level
ELCR	excess lifetime cancer risk
EnviroSystems	EnviroSystems Management, Inc.
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
ERT	Environmental Response Team
ESI	expanded site inspection
ESV	ecological screening value
Fe^{3+}	ferric iron
FeS_2	pyrite
FS	feasibility study
ft/ft	foot per foot
GEI	GEI Consultants, Inc.
GI	gastrointestinal
GIS	geographic information system

gpm	gallons per minute
GPS	global positioning system
Greenfields	Greenfields Enterprises, LLC
H:V	horizontal to vertical
Hcgl	Hickey Formation lower conglomerate
HHRA	human health risk assessment
HI	hazard index
HpCDD	heptachlorodibenzodioxin
HpCDF	heptachlorodibenzofuran
HQ	hazard quotient
HRS	Hazard Ranking System
HSCD	Humboldt Smelter Channel Deposit
Hunc	Hickey Formation upper conglomerate
HxCDD	hexachlorodibenzodioxin
HxCDF	hexachlorodibenzofuran
IEUBK	integrated exposure uptake biokinetic
IKV	Iron King Volcanics
IRIS	Integrated Risk Information System
IUR	inhalation unit risk
IVBA	in vitro bioaccessibility
kg	kilogram(s)
kg $CaCO_3$/tn	kilograms of calcium carbonate per metric ton
Kp	dermal permeability coefficient
Kuhles	Kuhles Capital, LLC
L	liter(s)
LANL	Los Alamos National Laboratory
lb	pound(s)
LCD	Lowermost Channel Deposit
LD_{50}	lethal dose for 50 percent of a population (or of test organisms)
LOAEL	lowest observed adverse effect level
Lockheed Martin SERAS	Lockheed Martin Scientific, Engineering, Response and Analytical Services
LOEC	lowest observed effect concentration
m^3/kg	cubic meters per kilogram
MATC	maximum acceptable toxicant concentration

MCL	maximum contaminant level
mg	milligram(s)
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/kg-day	milligrams of chemical per kilogram body weight per day
mg/L	milligrams per liter
mg/m^3	milligrams of substance per cubic meter of air
mg-year/kg-day	milligrams per year/kilograms per day
mm	millimeter(s)
mph	miles per hour
msl	mean sea level
MTP	Main Tailings Pile
NAAQS	National Ambient Air Quality Standards
NAI	North American Industries, Inc.
NNP	net neutralization potential
NOAEL	no observed adverse effect level
NOI	notice of intent
NOV	notice of violation
NP	neutralizing potential
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NPR	neutralization potential ratio
NRWQC	National Recommended Water Quality Criteria
NTP	National Toxicology Program
NTU	nephelometric turbidity units
OCDD	octachlorodibenzodioxin
OCDF	octachlorodibenzofuran
OPA	Ore Processing Area
ORNL	Oak Ridge National Laboratory
ORP	oxidation-reduction potential
PA	preliminary assessment
PAH	polycyclic aromatic hydrocarbon
Pb:Cu	lead to copper ratio
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin

PCDF	polychlorinated dibenzofuran
PeCDD	pentachlorodibenzofuran
PeCDF	pentachlorodibenzofuran
PFG	Principal Fluvial Gravels
PM_{10}	particulate matter less than 10 micrometers in diameter
PPRTV	Provisional Peer Reviewed Toxicity Value
PQ100	BGI PQ100 samplers
PVC	polyvinyl chloride
QAPP	quality assurance project plan
RAO	remedial action objective
RfC	reference concentration
RfD	reference dose
RI	remedial investigation
RME	reasonable maximum exposure
RSAR	Residential Screening Area Risk
RSL	Regional Screening Level
RYSR	Residential Yard-Specific Risk
SERAS	Scientific, Engineering, Response and Analytical Services
Settlement Agreement	Administrative Settlement Agreement and Order on Consent for Removal Action (EPA, 2006a)
SI	site investigation
Site	Iron King Mine – Humboldt Smelter Superfund Site
SLERA	screening-level ecological risk assessment
SMDP	Scientific Management Decision Point
SMS	Spud Mountain Series
SPLP	synthetic precipitation leaching procedure
SPT	standard penetration test
SVOC	semivolatile organic compound
SWPPP	stormwater pollution prevention plan
TAL	target analyte list
TCDD	tetrachlorodibenzodioxin
TCDF	tetrachlorodibenzofuran
TCRA	time-critical removal action
TDS	total dissolved solids
TEF	toxicity equivalency factor

TEOM	Thermo Electron TEOM Series 1400a
TEQ	toxicity equivalent
TIN	triangulated irregular network
TOC	total organic carbon
TPD	tons per day
TRV	toxicity reference value
TSP	total suspended particulates
UCD	Uppermost Channel Deposit
UCL	upper confidence limit
UF	uncertainty factor
USDI	U.S. Department of the Interior
USGS	U.S. Geological Survey
UTL	upper tolerance limit
VF	volatilization factor
VOC	volatile organic compound
VRP	Voluntary Remediation Program
XRF	x-ray fluorescence
yd^3	cubic yard(s)
Zn:Cu	zinc to copper ratio

SECTION 1

Introduction

The U.S. Environmental Protection Agency (EPA), under the authority of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended, has completed a remedial investigation (RI) of the Iron King Mine – Humboldt Smelter Superfund Site (the Site), located in Dewey-Humboldt, Yavapai County, Arizona. The Site includes two separate properties: the former Iron King Mine and former Humboldt Smelter. EPA combined the properties and contamination from the properties into one CERCLA site because of their proximity, because the respective operations involved the same types of potentially hazardous materials and contaminant sources, and because they resulted in commingled contamination in storm drainages and in the surrounding town.

The objective of the RI is to characterize conditions at the Site, determine the nature and extent of site-related contamination, and assess potential risks to human health and the environment. Based on the findings of the RI, as documented in this RI Report, EPA will screen, develop, and evaluate alternatives for remediation of contamination in a Feasibility Study (FS), and present those results in an FS report. In accordance with the CERCLA process, EPA will then select a remedy to eliminate, reduce, and/or control risks to human health and the environment associated with the Site.

This RI Report was prepared by CH2M HILL, Inc. (CH2M) for EPA Region 9 under EPA Contract Number EP-S9-08-04, Task Order Number 071-RICO-09MX.

1.1 Purpose of Report

This RI Report documents the history of the Site and evaluates data gathered through previous investigations and enforcement actions. The former Iron King Mine property and former Humboldt Smelter property both have long histories in the state of Arizona. Operations date back more than 100 years to the late 1800s. The Iron King Mine – Humboldt Smelter Superfund Site was established in 2008 to address site-related contamination. Extensive data have been collected over the years as EPA investigations and other actions have progressed.

The purpose of this RI Report is to:

- Provide a detailed description of the Site, including site setting, regulatory framework, history of operations and releases, previous investigations, and removal actions.
- Compile and present the results of Site investigations.
- Use the data gathered to:
  - Describe the nature and extent of site-related contamination in impacted soil, sediment, surface water, groundwater, and ambient air.
  - Determine the risk posed by site-related contamination to human health and the environment.
  - Evaluate the fate and transport of contamination in impacted media.

This RI Report was developed in accordance with the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988).

1.2 Site Overview

The Site is a combination of the contaminant sources, contaminant releases, and areas to which contamination has come to be located, that originated from various operations at the former Iron King Mine and the former Humboldt Smelter. The two former facilities are located approximately 0.5 mile from each other in the high desert of central Arizona in Yavapai County, about 85 miles north of Phoenix.

Both properties lie within the current boundary of the Town of Dewey-Humboldt, Arizona (Figure 1-1). Dewey-Humboldt has a population of approximately 4,000 and was incorporated in 2004 as a merger of the unincorporated communities of Dewey (historically an agricultural and ranching economy) and Humboldt (historically a mining-based economy) (Town of Dewey-Humboldt, 2014). The approximate centers of the original communities are shown as “Dewey Proper” (also referred to as “Dewey” in this RI) and “Humboldt Proper” (also referred to as “Humboldt” in this RI) on Figure 1-1. More information about the town is provided in Section 2 (Site Description and History).

The contaminant sources at the former mine and smelter properties are associated primarily with stockpiled mine and smelter waste created during a long history of operations beginning in the late 1800s. Release and transport of contamination resulted from a number of processes, including historical operational discharges, impoundment failures, placement of mine and smelter waste in drainages or on nearby properties, erosion during storm events, spills during transport along rail routes, smelter stack emissions, windblown particulates, use of mine waste material as fill material or road base, and redistribution of contamination during development. Site contaminants, primarily metals such as lead and arsenic, have impacted neighboring residential and municipal properties.

Transport of contaminants via surface water occurred through discharge to one of two intermittent surface water features: Chaparral Gulch and Galena Gulch (Figure 1-1).

- Chaparral Gulch is an intermittent drainage that flows southeast through parts of both properties and intersects with the Agua Fria River on the southeast side of the former Humboldt Smelter property.
- Galena Gulch is an intermittent drainage that crosses the southwest corner of the former Iron King Mine property and flows south/southeast to intersect the Agua Fria River about 1 mile downstream of the Chaparral Gulch-Agua Fria River confluence.

The Agua Fria River is the primary surface water feature in the area. In the vicinity of the Site, the Agua Fria River is perennial and flows south through portions of the eastern section of the former Humboldt Smelter property in a narrow canyon incised into volcanic rocks and underlying bedrock. Surface water and sediment in portions of Chaparral Gulch, Galena Gulch, and the Agua Fria River have been impacted by Site contamination.

The following subsections provide a brief overview of operations at the former Iron King Mine and Humboldt Smelter properties. Details on contaminant sources and operational history are provided in Section 2 (Site Description and History).

1.2.1 Former Iron King Mine Property

The former Iron King Mine property consists of about 150 acres located on the west side of State Highway 69 (Figure 1-2). A large portion of the property is currently covered with tailings and waste rock piles. "Tailings” are the byproducts from processing and concentrating the ore to extract the target metals; “waste rock” is the rock that overlies or surrounds the ore body and is displaced during mining. North American Industries (NAI) currently owns the eastern portion of the former Iron King Mine property and produces Hydromax fertilizers and soil supplements (ACS, 2008). Several stormwater retention ponds are used to control surface water flow around the stockpiled tailings and the NAI Operations area. A residential area is located northeast of the NAI Operations area.

Mining was performed from the late 1890s to 1968, with production peaking in 1963 (ACS, 2008). Ore produced from the former Mineworks area (Figure 1-2) was milled and concentrated onsite. Mill waste (tailings) was stockpiled onsite. Mill product (primarily lead and zinc concentrate) was shipped offsite for smelting and metal recovery. A total of 6.3 million tons of ore was produced from Iron King Mine while it was active (USGS, 1995).

Production of fertilizer from the accumulated tailings was initiated in 1960. The initial fertilizer operation was located in the southwestern part of the property, in a portion of the former Mineworks area (Figure 1-2). The fertilizer was historically sold as products called “Superferrite” and “Ironite.” After cessation of mining operations in 1968, production of fertilizer continued at the former Fertilizer Plant until 1988, when operations moved to the current location in the eastern part of the property. The market for the powdered fertilizer product Ironite collapsed after buyers discovered that it contained high levels of arsenic, and Ironite Products Company transferred ownership to NAI in 2006. NAI intends to produce a new liquid fertilizer product called Hydromax from the tailings. NAI claims that its manufacturing process for Hydromax removes the lead and arsenic from the tailings. This would represent a resumption of the commercial re-mining of the tailings after the demise of the Ironite Fertilizer operation. It is unclear at this time whether such commercial plans will be found consistent with the remedies to be selected by EPA for the Site.

The primary stockpile of tailings remaining on the Iron King Mine property is the Main Tailings Pile (MTP), with a volume of approximately 3.5 million cubic yards (yd^3). NAI currently owns the majority of the MTP. A Small Tailings Pile, removed by EPA in 2011 and consolidated with the MTP, was located to the north of the former Iron King Mine property boundary (Figure 1-2).

1.2.2 Former Humboldt Smelter Property

The former Humboldt Smelter property consists of about 180 acres and is located about 0.5 mile east of State Highway 69. Access to the property is at the southeastern end of Main Street, south of the Third Street/Main Street intersection (Figure 1-3). There are no facility operations or businesses currently operating on the property. Current features on the property include: (1) approximately 20 acres of yellow-orange tailings in the Smelter Tailings Swale and the Tailings Floodplain; (2) approximately 15 acres of imported dross on the ground and in piles in and around the former Pyrometallurgical Operations area (“dross” is a waste product taken off the surface of molten metal during smelting); (3) approximately 8 acres of slag piles east of the former Pyrometallurgical Operations area; and (4) the Smelter Plateau, which formerly contained operations and housing structures. Also, smaller tailings piles are located along the Agua Fria River and Chaparral Gulch near their confluence; these tailings were generated through a series of mining and smelting operations beginning in the late 1870s.

The former Humboldt Smelter property has housed at least three separate smelters and one historical mine over time as discussed below:

- The Agua Fria Ore Mill and Smelter was constructed at the property in the late 1870s and closed in the mid-1880s. Site records indicate the mill was located in the southeastern corner of the former Humboldt Smelter property, near the confluence of the Agua Fria River and Chaparral Gulch (see Figure 1-3). Ore for the Agua Fria Ore Mill and Smelter was obtained from a local mine known as the Chaparral Gulch Shaft (Figure 1-3) and the Silver Belt Mine located about 5,500 feet southwest of Iron King Mine.
- The Val Verde Smelter was constructed beginning in 1899 in the eastern portion of the former Pyrometallurgical Operations area; this smelter operated from 1901 to 1904. The copper-rich ore was shipped to the smelter by rail. The rail spur for the smelter ran through central Humboldt and entered the facility near what is now Sweet Pea Lane (Figure 1-3). The Val Verde Smelter was destroyed by fire in 1904.
- The Humboldt Smelter was constructed in 1906. The smelting operations included facilities to mill the ore and to smelt the copper concentrate produced by the mill. Most of the smelting operation

infrastructure was located in the northern portion of the property (the former Pyrometallurgical Operations area [Figure 1-3]).

The site record suggests that Iron King Mine did not routinely send ore to the Humboldt Smelter for processing because of the difference in mineral composition between the Iron King Mine concentrate and the Humboldt Smelter feed, and because peak production periods did not overlap.

By 1937, ore reserves from nearby mines were exhausted, and the Humboldt Smelter ceased primary smelting operations (ACS, 2008). The Humboldt Smelter was closed and dismantled after World War II. In the late 1950s and early 1960s, a large quantity of dross was imported from California and Texas to the former Humboldt Smelter Property for reprocessing to recover zinc and aluminum (ACS, 2008). The source of the dross may have been die-casting plants; based on the fact that the dross found at the Site is fine and uniform, it is probable that the material was processed (for example, by milling) before being imported to the Site. The dross operations continued until 1970. Several other small-scale industrial businesses occupied the property prior to its conversion to a wooden-pallet-producing facility, which closed in 1974.

1.3 Remedial Investigation Basis and Overview

The following section provides an overview of the various investigations and actions performed for the Site. These are described in more detail in Section 3 (Regulatory Framework, Preliminary Investigations, and Removal Actions) and Section 4 (Remedial Investigations).

1.3.1 Basis of this Remedial Investigation Report

Large quantities of waste materials generated by previous operations remain at the former Iron King Mine and former Humboldt Smelter properties. Historical releases of contamination have occurred at both properties. Numerous investigations and enforcement actions have been conducted by EPA, the Arizona Department of Environmental Quality (ADEQ), and others to address conditions at the Site and surrounding areas. This has included initial remedial (and supporting) investigations, supplemental RIs, removal actions, background studies, data gap investigations, and ancillary investigations conducted under the data gap investigations.

This RI Report is a synthesis of the previous and current investigations and provides additional analysis, evaluation, and risk assessment conducted by EPA and CH2M in 2015/2016. The result is the most comprehensive understanding of the Site to date. This RI Report will be used to support decisions needed to move the CERCLA process forward to the FS phase.

1.3.2 Overview of Past Activities

At EPA's request, ADEQ completed a Preliminary Assessment/Site Investigation (PA/SI) of the Iron King Mine property in 2002 (Section 3.3.1), a PA/SI of the Humboldt Smelter property in 2004 (Section 3.3.2), and an Expanded Site Investigation (ESI) for the combined Site in 2006 (Section 3.3.4).

The purpose of a PA/SI (and ESI) is to collect information to assess whether a release of hazardous substances to the environment has occurred, to determine whether additional investigation is required, and to aid in decisions regarding whether or not to place a site on the National Priorities List (NPL). The PA/SI conducted at both the former Iron King Mine property and the former Humboldt Smelter property and the subsequent ESI for the combined Site identified metals contamination in soil, sediment, surface water, and groundwater. ADEQ and EPA concluded that further investigation was warranted.

In 2005, ADEQ requested that EPA conduct a removal assessment to identify off-property impacts to surface soil at residential properties along Chaparral Gulch near the Iron King Mine (Section 3.3.3). An Administrative Settlement Agreement between EPA and Ironite Products Company (then-owner of a portion of the Iron King Mine property) was signed in 2006. Under this agreement, Ironite Products

Company performed a removal action at four residential properties (Section 3.4.1). At EPA's request, Ironite Products Company also performed site characterization activities in March and June of 2008 that included sampling soil and surface water at and near the former Iron King Mine (Brown and Caldwell, 2009b) (Section 3.3.5).

Based on the findings of these early investigations, EPA determined that NPL listing was appropriate to address, in a comprehensive manner, contamination associated with the former Iron King Mine and Humboldt Smelter properties, the connecting drainage features, and residential areas in Dewey-Humboldt potentially impacted by mining or smelting operations. EPA placed the Site on the NPL in 2008.

Between 2008 and 2015, EPA performed four primary phases of investigations at the Site (Section 4). The broad objectives of these investigations were to: (1) identify source areas and historical releases; (2) evaluate the nature and extent of contamination; (3) develop a conceptual site model (CSM); (4) evaluate the fate and transport of contamination; (5) assess human health and ecological risks; and (6) perform other studies to support the evaluation of potential remedial alternatives. EPA's focus was to assess impacts from metals associated with mine and smelter operations, including arsenic and lead. During this time period, EPA also performed a time-critical removal action (TCRA) at nearby properties within the Town of Dewey-Humboldt.

Phase 1 of the RI was performed by EPA contractor EA Engineering, Science, and Technology, Inc. (EA) during several mobilizations in 2008 and 2009 (EA, 2010) (Section 4.2). EA's work during Phase 1 included:

- Collection and analysis of soil and sediment samples from the former Iron King Mine and Humboldt Smelter properties
- Collection and analysis of soil samples from residential, commercial, and public properties in the Town of Dewey-Humboldt
- Collection and analysis of groundwater samples at six new groundwater monitoring wells and private water supply wells
- Collection and analysis of surface water and sediment samples along the Agua Fria River, Galena Gulch, and the Chaparral Gulch
- Collecton and analysis of ambient air in the mine and smelter properties, the Humboldt Elementary School, and residential areas

Several supporting studies were also performed or documented in 2007 through 2010 (Section 4.2.7), concurrent with the EA initial investigations; the supporting studies included:

- A biological evaluation (EnviroSystems, 2009)
- A cultural resource and historic building survey for the mine and smelter properties (ACS, 2008)
- An analysis of historical aerial photographs for the mine and smelter properties and adjacent areas (EPA, 2008d)
- A wetland delineation and riparian evaluation of lower Chaparral Gulch (WestLand Resources, Inc., 2009)
- Several research projects completed through the University of Arizona Superfund Basic Research Program (EA, 2010)
- A reuse assessment for the mine and smelter properties (E2 Inc., 2010)

After reviewing the initial results of these investigations, EPA identified additional data needs. To fill these data needs, EA performed Phase 2 of the RI in 2010 (Section 4.3) on behalf of EPA (EA, 2011). Phase 2 of the RI included:

- Collection and analysis of additional soil samples from source areas to assess whether the media exceeded the criteria for a characteristic hazardous waste
- Collection and analysis of soil samples from additional residential, commercial, and public properties in the Town of Dewey-Humboldt to assess the distribution of metals
- Collection and analysis of soil samples from background locations to assess naturally occurring levels of metals in soil
- Collection and analysis of groundwater samples from existing EPA monitoring wells, private supply wells, and municipal wells, and installation of six additional monitoring wells in 2012
- Evaluation of preliminary cover options for the MTP (GEI, 2010)
- Collection of geotechnical data to evaluate the stability of the MTP (GEI, 2012)

Beginning in the fall of 2010, EPA performed a removal assessment for properties in the Town of Dewey-Humboldt (Section 3.4.2). In response to elevated concentrations of arsenic and lead in surface soil, EPA conducted a TCRA in 2011 (Section 3.4.2) for 10 residential properties, 1 municipal property, and the Small Tailings Pile north of the former Iron King Mine property (E & E, 2012).

During the initial and supplemental phases of the RI, significant numbers of samples had been collected in residential areas close to the former Iron King Mine and Humboldt Smelter properties, primarily to the north of and between the properties. Arsenic was identified as a primary risk driver. One of the major challenges for assessing Site arsenic impacts, however, was that while arsenic contamination is related to the mine and smelter operations, it also occurs naturally at highly variable concentrations in the surrounding rocks and soils. The data coverage was insufficient to account for variations in geology and natural soil chemistry as well as the multiple sources of metals. In 2012 and 2013, EPA staff performed Phase 3 of the RI. During Phase 3, EPA staff collected soil samples over an area of approximately 20 square miles, in part to better characterize variations in metals concentrations at locations that were not expected to be impacted by the mine- and smelter-related sources (Section 4.4).

The data collected during Phase 3 of the RI were used in combination with soil data collected as part of other site investigations to establish representative background concentrations. CH2M developed an approach using site-related indicator parameters (copper and zinc) and ratios of shallow to deep metals concentrations to differentiate between site-affected areas and background areas (CH2M, 2015). This approach allowed the calculation of defensible background concentrations for arsenic, lead, and other metals, and established an approximate geographic extent of potential site-related impacts that bounded the extent of investigation during subsequent investigations. This area is referred to as the area of potential site impact (APSI) and is discussed in more detail in Section 6.

In 2013, EPA and its contractor CH2M reviewed the earlier investigation findings to assess whether sufficient information was available to determine the nature and extent of contamination, complete the human health and ecological risk assessments, and develop and evaluate alternatives in the FS (CH2M, 2013) (Section 4.5). A summary of the most significant data gaps identified is provided below; additional details are presented in Section 4.5.1.

- Source Areas (Iron King Mine, Humboldt Smelter, and lower Chaparral Gulch):
  - Distribution, volume, stability, and acid-generating potential of mine and smelter wastes had not been adequately characterized.

- Potentially Impacted Areas:
  - Further delineation of impacted soil was required on undeveloped properties near the mine and smelter and residential and commercial properties in Dewey-Humboldt.
- Sitewide Groundwater and Surface Water:
  - New monitoring wells were required to assess groundwater flow directions and gradients, geology and hydrogeology, and groundwater quality.
  - Limited flow and water quality data were available in Chaparral Gulch.
- Risk Assessment Data Collection:
  - Additional data were required to assess the site-specific bioaccessibility of arsenic and lead.
  - Reconnaissance-level biological survey, and biological and collocated soil samples were recommended.
  - Additional surface water and sediment sampling was recommended in Chaparral Gulch and the Agua Fria River.

EPA requested assistance from the EPA/Environmental Response Team (ERT) to perform Phase 4 of the RI to address the data gaps identified. Lockheed Martin personnel from Scientific, Engineering, Response and Analytical Services (SERAS; also known as Lockheed Martin SERAS) assisted EPA/ERT with this work, which was performed between 2013 and 2015. EPA/ERT and Lockheed Martin SERAS conducted an extensive field investigation and associated analyses that included the following (further details of these activities are provided in Section 4.5.2 through 4.5.17):

- An extensive subsurface investigation of Chaparral Gulch, Tailings Floodplain, and Humboldt Smelter Swale
- Geophysical surveys of the Smelter Tailings Swale and Tailings Floodplain
- Investigations to characterize Humboldt Smelter dross, slag, and plateau soils
- Investigations to characterize the MTP and waste rock areas at the Iron King Mine
- Installation of new groundwater monitoring wells, collection and analysis of groundwater samples from new and existing monitoring wells, and development of a conceptual geologic model
- Collection and analysis of surface water and sediment samples from Chaparral Gulch and the Agua Fria River near the Site
- Channel surveys and flow monitoring in lower Chaparral Gulch
- Biological survey within the Agua Fria River and bioassessment sampling at various locations at the Site
- Soil ecological testing on the Tailings Floodplain
- Collection and analysis of soil samples in residential and non-residential areas of Dewey-Humboldt, the scope of which was expanded significantly relative to the previous investigations
- Additional studies and analyses to support risk assessments and evaluation of alternatives, including:
  - Modeling to assess volumes of tailings and contaminated soil and Chaparral Gulch, Tailings Floodplain, and Humboldt Smelter Swale
  - Modeling to assess volumes of dross and contaminated soil at the Humboldt Smelter

  - Topographic surveys
  - Soil ecological testing
  - Construction material survey
  - Structural condition assessment of the Humboldt Smelter stack

In total, approximately 10,000 soil samples, 300 sediment samples, and 130 surface water samples were collected and analyzed during the investigations performed after the Site was listed on the NPL. In addition, EPA installed and sampled 26 monitoring wells, collected groundwater samples from private and municipal supply wells, and collected approximately 280 ambient air samples from 10 locations. EPA and its contractors consolidated data from the various phases of the RI with earlier pre-NPL investigations into a comprehensive Site database.

To aid in the evaluations presented in this RI Report, EPA subdivided the Site into separate exposure areas based on current or future land use, former operations, waste types and source materials, and property boundaries. Chemicals of interest (COIs) were identified by comparing results to background concentrations and human health and ecological screening levels. The nature and extent of contamination based on these COIs was defined, human health and ecological risks were assessed, and the fate and transport of the associated contamination were evaluated. The findings of these evaluations have been used to identify contaminated media and exposure areas for which remedial alternatives will be developed in the FS.

1.4 Report Organization

This RI Report is organized into the following sections:

- **Section 1 – Introduction.** This section presents the purpose of the report, an overview of the Site, an overview of the RI process, and the organization of this RI Report.
- **Section 2 – Site Description and History.** This section provides a description of the Site features, a history of mining and smelting operations at the Site, and a summary of the source areas and historical releases.
- **Section 3 – Regulatory Framework, Preliminary Investigations, and Removal Actions.** This section presents a discussion of the regulatory framework, preliminary investigations performed prior to inclusion of the Site on the NPL, and removal actions performed to address impacts to offsite properties.
- **Section 4 – Remedial Investigations.** This section provides the objectives, methods, and details of the investigations performed after the Site was listed on the NPL.
- **Section 5 – Physical Site Characteristics.** This section summarizes the physical characteristics of the Site including the physiographic setting, meteorology, surface water features, geology, hydrogeology, ecological setting, demographics, and land use.
- **Section 6 – Data Evaluation Methodology.** This section describes the methodology used to compile, review, and evaluate data to assess the nature, extent, fate, and transport of contamination and prepare the baseline risk assessments for the Site. It includes a discussion of data usability and processing, estimation of background concentrations, identification of the APSI, the selection of screening levels to assess contamination in Site media, the identification of COIs and exposure areas within the APSI, and methods used to calculate the source material volumes.

- **Section 7 – Nature and Extent of Contamination.** This section describes the nature and extent of contamination at the Site. It includes a discussion of soil contamination at the source areas and other potentially impacted areas within the APSI, as well as a discussion of the sitewide groundwater, surface water, sediment, and ambient air contamination.
- **Section 8 – Contaminant Fate and Transport.** This section presents the CSM and an evaluation of COI fate and transport in the environment.
- **Section 9 – Baseline Human Health Risk Assessment (HHRA).** This section presents the results of the human health exposure assessment, toxicity assessment, and risk characterization.
- **Section 10 – Baseline Ecological Risk Assessment (ERA).** This section presents the results of the ecological exposure assessment, toxicity assessment, and risk characterization.
- **Section 11 – Summary and Conclusions.** This section summarizes the RI activities and results, and provides the conclusions of the RI. It also identifies the exposure areas and media at the Site for which remedial alternatives should be developed in the FS.
- **Section 12 – Works Cited.** This section lists sources of information referenced in this RI Report.
- **Tables** and **Figures.** Tables and figures are provided in sections following the text.

Appendixes provide supporting materials to document the site history, current site conditions, removal actions, nature and extent evaluation, and risk assessments. The following appendixes are included with this report:

- **Appendix A: Current Site Photographs.** A photographic log that illustrates current Site conditions.
- **Appendix B: Cultural Resource and Historic Building Survey.** Report that documents the historical information, cultural resources, and a historic building survey of the Site (ACS, 2008).
- **Appendix C: Aerial Photographic Analysis.** An EPA report that documents and analyzes aerial photographs of the Iron King Mine and Humboldt Smelter properties (EPA, 2008d).
- **Appendix D: Interim Removal Action Reports.** The source documents describing each of the removal actions.
- **Appendix E: Soil Background Study Report.** The report titled, *Soil Background Study Report, Iron King Mine – Humboldt Smelter Superfund Site, Dewey-Humboldt, Yavapai County, Arizona* (CH2M, 2015).
- **Appendix F: EPA Environmental Response Team (ERT) Data Gap Remedial Investigation Report.** Report that documents the EPA/ERT RI investigations performed in 2013 through 2015 (Lockheed Martin SERAS, 2015).
- **Appendix G: Analytical Data.** Site database with tables summarizing the analytical results by media.
- **Appendix H: Derivation of a Site-Specific Oral Bioavailability Adjustment Factor for Arsenic in Soil.** Documentation of development of the site-specific arsenic bioavailability adjustment factor.
- **Appendix I: Evaluation of Tailings Mixing in Chaparral Gulch and the Tailings Floodplain.** Statistical comparison of key geochemical properties that can be used to differentiate the source of tailings as being from either the Iron King Mine site or the Humboldt Smelter site.
- **Appendix J: Residential Sampling Results and Yard-Specific Maps.** Summary of analytical results, lead concentration maps, and arsenic concentration maps for residential yards sampled during the RI.
- **Appendix K: Supplemental HHRA Information.** Supplemental information used to perform HHRA calculations.

- **Appendix L: Toxicological Fact Sheets for Arsenic and Lead.** Toxicological fact sheet information for arsenic and lead.
- **Appendix M: Supplemental ERA Information.** Supplemental information used to prepare the ERA.
- **Appendix N: Air Monitoring Data.** Tables and figures of air monitoring data from the 2008 to 2009 Initial RI report (EA, 2010).
- **Appendix O: Mine Workings and Sanborn Fire Insurance Maps.** Supplemental information to support the site history and site feature descriptions, including plates of the Iron King Mine workings and Sanborn Fire Insurance Maps.

SECTION 2

Site Description and History

This section provides a site description and history of operations at the former Iron King Mine and former Humboldt Smelter properties. Section 2.1 describes the primary current site features including the Town of Dewey-Humboldt and the former mine and smelter properties (a brief overview of historical mining and smelting operations is also provided here for context). Section 2.2 presents the history of the town and its relationship to operations at the former Iron King Mine property and former Humboldt Smelter property. Section 2.3 provides additional details relating to the former mining and smelting operations. Section 2.4 presents a summary of source areas and historical releases.

2.1 Site Features

The relevant Site features and setting are listed below and described in the following subsections:

- Town of Dewey-Humboldt
- Former Iron King Mine property
- Former Humboldt-Smelter property
- Surface Water Features

Figures 2-1 through 2-3 show detailed historical features of the former Iron King Mine and former Humboldt Smelter properties. Appendix A includes a photographic log showing current conditions.

2.1.1 Town of Dewey-Humboldt

The Town of Dewey-Humboldt is located at the southeastern end of Lonesome Valley in Yavapai County, Arizona. The town covers an area of about 12,000 acres or 19 square miles, and is located at an elevation of about 4,600 feet. State Highway 69 transects the town north to south. State Highway 169 begins at State Highway 69 and crosses the northeastern portion of the town.

Existing land uses within the Town of Dewey-Humboldt include small farms, some higher-density urban development with adjacent commercial uses, and single-family residential neighborhoods (Town of Dewey-Humboldt, 2009). The 1.25-million-acre Prescott National Forest is located adjacent to the town. Roughly half of the forest lies west of the Town of Dewey-Humboldt and includes the Bradshaw Mountains; the other half of the forest lies east of the town and includes the Black Hills (U.S. Forest Service, 2016).

The town is governed by a mayor and vice mayor and a five-member Town Council (Town of Dewey-Humboldt, 2014). The Town Council is committed to maintaining the rural flavor of the area (Arizona Commerce Authority, 2015).

As discussed in Section 1 and shown on Figure 1-1, the former Iron King Mine and Humboldt Smelter properties lie within the current boundary of the Town of Dewey-Humboldt. Humboldt Proper, which includes residential and commercial development, is located north of and adjacent to the smelter property and northeast of the former mine property (Figure 1-1).

Soil on some residential and municipal properties within the Town of Dewey-Humboldt has been impacted by historical mining and smelter operations and contaminant migration from source areas. Sources include historical Humboldt Smelter stack emissions; windblown tailings, dross, or fine-grained particulates; tailings deposition along drainages; spills and material releases along historic rail routes; and use of mine waste material (tailings, waste rock) as fill material or road base. Development of the area during the more than 100 years since operations began at the former mine and smelter properties has resulted in the redistribution of contamination. For example, moving, cutting, and filling material within residential or commercial properties, construction activities, and changes in land use have impacted the contaminant distribution. Other non-site-related sources of arsenic and lead have also been introduced, including importing fill from quarries with naturally elevated concentrations of arsenic, use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires. Two removal actions have been conducted at residential and municipal properties in response to the detection of concentrations of arsenic and lead in surface soil exceeding remedial action (or "cleanup") levels set by EPA (these removal actions are discussed further in Section 3.4).

Eighty percent of town residents rely on water rights from private exempt wells (less than 35 gallons per minute [gpm] each). The remaining residents are supplied water from private water companies including Humboldt Water Company, which services the south-central portion of town near the Site, and the Wilhoit Water Company, which services the north-central portion of the town (ADEQ, 2006; Town of Dewey-Humboldt, 2009; E2 Inc., 2010). In 2014, Humboldt Water Company supplied drinking water from municipal wells to approximately 330 households (Arizona Corporation Commission Utilities Division, 2015).

The majority of the town lies within the Prescott Active Management Area (AMA) (Town of Dewey Humboldt, 2009; E2 Inc., 2010). AMAs were designated under the 1980 Arizona Groundwater Code to conserve and sustain water resources of the State. In the Prescott AMA, the primary management goal is safe-yield (which means that the amount of groundwater withdrawn is no greater than the amount of groundwater replaced on an annual basis) by the year 2025 (Arizona Department of Water Resources, 2014).

EPA has sampled numerous private and municipal drinking water wells as part of Site investigations. See Sections 3 and 4 for additional discussion of pre-NPL and RI sampling activities, respectively, and Section 5 for further discussion of water supply and production wells in the area. Section 5 also presents additional details on the Town of Dewey-Humboldt, including demographics and land use.

2.1.2 Former Iron King Mine Property

Relevant features of the former Iron King Mine property include the following (these are illustrated on Figures 1-2 and 2-1):

- Former Mineworks area and former Glory Hole
- MTP
- Former Small Tailings Pile
- Former Fertilizer Plant area
- NAI Operations area (currently operational)

Each of these features is discussed below, along with a brief overview of historical operations (described in more detail in Section 2.3).

2.1.2.1 Former Mineworks Area and Former Glory Hole

The former Mineworks area and former Glory Hole are located in the western/southwestern portion of the Iron King Mine property. The former Mineworks area includes the mine headworks and shafts. Ore-concentrating operations occurred in the former Mineworks area.

When the former Mineworks area was in operation, ore was hoisted from the mine shafts and transported to the mill for processing. The primary access to the mine workings was via vertical shafts rather than horizontal entrances, or adits, because of the location and orientation of the ore deposit relative to ground surface. Figure 2-1 shows the known locations of the mine shafts; plates of the mine workings are included in Appendix O. The Iron King Mine workings extend more than 1,000 feet southwest of the Iron King property boundary (see Map Label 14 indicating the approximate southwestern end of the 100 level). Shafts 1 and 5 are located south of the former Iron King Mine property boundary near Galena Gulch, while Shafts 2, 6, and 7 are located in the former Mineworks Area. Shafts 3 and 4 are caved and records do not indicate their locations (USGS, 1958).

The mining and ore processing methods varied over time, but the typical operation was to hoist the ore from the mine, dry crush it, and then wet grind it in ball mills. As part of the grinding circuit, ore was classified (that is, separated by particle size) and the coarse material was recycled to the grinding mills for additional grinding. During peak production years, the mineral recovery circuits after grinding were quite complex with separate lead and zinc flotation steps (producing separate lead and zinc concentrates) as well as gravity concentration tables for additional lead recovery. Concentrates were dewatered using thickeners, filters, and dryers. Tailing slurries were thickened prior to discharge to the tailings ponds (ACS, 2008).

Concentrates were then hauled by truck roughly 1 mile to a railroad siding where they were loaded onto railcar bins for transport to various smelters for processing (EPA, 2009c). The Iron King Spur of the historic Prescott and Eastern Railroad serviced the mine (see historic rail line on Figure 1-2). Evidence suggests the Iron King Mine did not routinely send ore or concentrates to the smelter operations at the former Humboldt Smelter property for processing, with the exception of some material that was tested at the smelter for suitability as a flux in its processes (see Section 2.3.1 for further discussion of the relationship between Iron King Mine and Humboldt Smelter operations).

A large portion of the former Mineworks area is now covered with a surface deposit of rock removed from the mine to access the Iron King Mine ore body (also known as “waste rock”). This waste rock exhibits varying levels of mineralization and elevated concentrations of metals.

Ten buildings remain standing in the former Mineworks area (Figure 2-1). These buildings were used for various heavy industrial operations (such as ore processing). The standing structures were built between 1950 and 1990 and include the head frame for Mine Shaft No. 7, a large concrete cistern, and several industrial buildings. In addition, numerous concrete foundations and rubble piles mark the location of former buildings.

The former Glory Hole was created when a mining technique called “block caving” set off a chain of events that caused all levels at the north end of the mine to collapse (ACS, 2008). The Glory Hole was later used by Kuhles Capital, LLC (Kuhles) as a landfill for municipal waste, construction debris, and tires. ADEQ was responsible for the permit to operate this facility, and ultimately revoked the permit and required closure, which included regrading and construction of a final cover.

2.1.2.2 Main Tailings Pile

The MTP consists of milled waste (tailings) deposited on the former Iron King Mine property as part of the mining operation. The MTP has an area of about 55 acres. The volume of tailings in the MTP is estimated at approximately 3.5 million yd^3. The MTP includes an upper tailings pile (upper MTP) that is up to 105 feet thick, and a lower tailings pile (lower MTP) that is up to 60 feet thick (GEI, 2012). The surface of the MTP is largely crusted and cemented. Soil borings indicate that the surface of the MTP is oxidized and appears yellow to orange, but beyond a few feet below the surface, tailings are present under reducing conditions (in the absence of oxygen) and are dark green. The grain size of the tailings is uniform and predominantly silt size. Several stormwater retention ponds are used currently to control surface water flow from the MTP (Figure 2-1). There are widespread efflorescent salts on the MTP from frequent wetting and drying. Photographs 2 through 8 in Appendix A show the MTP.

The MTP was originally developed as a series of smaller impoundments within two shallow drainages that were tributaries to Chaparral Gulch. Construction details of the tailings dams used to retain the MTP are not well documented. The record does suggest that tailings were used to raise the embankments, with coarse material deposited near the embankment at the perimeter of the tailings pile and finer material deposited further from the discharge point.

The southeastern slope of the upper MTP is approximately 100 feet high and steep (approximately 2:1, horizontal to vertical [H:V]). On March 23, 1964, during a period of high rainfall, a portion of this slope failed resulting in the largest known tailings release event (Kentro, 1964; GEI, 2010). This event has been termed the "MTP Blow Out." A significant portion of the tailings slumped and accumulated on the former Iron King Mine property behind a berm formed by the historic rail bed west of State Highway 69. This tailings slump formed what is now referred to as the lower MTP (Figure 2-1). Some of the released tailings (likely finer-grain-size) were transported east of State Highway 69, parallel to the current location of Third Street, and into Chaparral Gulch. The failure left a rough gouge approximately 300 feet wide on the face of the MTP that is subject to heightened erosion (see Photographs 2 and 5 in Appendix A).

The tailings have remained in their current configuration, with the exception of surface erosion, since an aerial photograph taken in 1973 (EPA, 2008d). There are a number of erosion channels and rills that occur on the steep perimeter side slopes. The failure on the southeastern slope continues to promote further erosion of the exposed tailings pile. Further details on the MTP developmental history and the MTP Blow Out are presented in Section 2.3.

2.1.2.3 Former Small Tailings Pile

The former Small Tailings Pile was located north of the MTP and outside the former Iron King Mine property boundary on a parcel zoned for residential use (Figure 2-1). It was located along a drainage tributary to Chaparral Gulch, which borders the pile to the north and east. The Small Tailings Pile was an accumulation of tailings material likely produced by cyanidation of the mill tailings for gold and silver recovery (E & E, 2012). Historically, these tailings were hydraulically conveyed from the former Mineworks area to the impoundments that formed the Small Tailings Pile (Figure 2-1).

During the 2008 to 2009 Initial RI, EA observed there were no stormwater controls mitigating surface water migration from the Small Tailings Pile, and much of the area was devoid of vegetation (EA, 2010; E & E, 2012). EPA completed a TCRA in 2011 that included removal of the Small Tailings Pile and consolidation with the MTP. The volume of material removed was 21,500 yd^3. Following removal, EPA restored the grades and drainage patterns in the former Small Tailings Pile area to convey stormwater to Chaparral Gulch and protect against future erosion. Restoration included placement of coarse riprap and construction of a 400-foot diversion channel (E & E, 2012).

2.1.2.4 Former Fertilizer Plant Area

The former Fertilizer Plant was located in the southern portion of the former Mineworks area on the south side of Iron King Road (Figure 2-1). The fertilizer operation began in 1960 and continued until a new (and the current) fertilizer facility was constructed in 1988 in the NAI Operations area on the eastern portion of the Iron King Mine property. Aqua Tec, LLC (Aqua Tec) operated a permitted septic tank sludge (septage) treatment facility in the former Fertilizer Plant area from 2003 until 2005 (see Section 3.2.1 for further discussion on this permit). Currently, this area is mostly covered by waste rock surface deposits and tailings, as well as abandoned buildings, pads, sumps, tanks, and an ore bin (EA, 2010). As shown on Figure 2-1, Shaft 2 of the former Iron King Mine was located in this area.

2.1.2.5 NAI Operations Area

NAI currently owns the MTP and owns and operates a fertilizer and soil supplement production facility adjacent to and north of the MTP. The NAI Operations area includes fertilizer production buildings, warehouses, and an office that were built starting in 1988 (Figure 2-1). Tailings from the MTP are screened, stockpiled, and processed to produce a liquid fertilizer product called Hydromax. Several stormwater retention ponds are currently used to control surface water flow around the Iron King Mine MTP and NAI Operations area in accordance with the *Storm Water Pollution Prevention Plan, North American Industries – Humboldt Plant* (Brown and Caldwell, 2009a). The most significant of these ponds are individually labeled on Figure 2-1.

2.1.3 Former Humboldt Smelter Property

Relevant features of the former Humboldt Smelter property are shown on Figures 1-3 and 2-2 and include the following:

- Former ore concentration area
- Former Pyrometallurgical Operations area
- Dross area
- Slag piles
- Smelter Plateau
- Smelter Tailings Swale
- Tailings Floodplain
- Lower Chaparral Gulch
- Agua Fria Tailings Pile

These features are primarily located adjacent to or north of Chaparral Gulch and west of the Agua Fria River. Some of these features are no longer present in their original form, but are important to discuss as sources of contamination that remain on the property. Each of these features is discussed below, along with a brief overview of historical operations (described in more detail in Section 2.3). As shown on Figures 1-3 and 2-2, the former Humboldt Smelter property also includes undeveloped land located southwest of Chaparral Gulch and undeveloped land east of the Agua Fria River (on a plateau above the Agua Fria River canyon). No historical operations were known to occur on these portions of the former Humboldt Smelter property.

2.1.3.1 Former Ore Concentration Area

An ore concentrator was located to the west of the former Pyrometallurgical Operations area, north of the Smelter Tailings Swale and adjacent to the network of rail spurs that entered the Humboldt Smelter from the northwest (Figure 2-2). The location of the ore concentration facility shown on Figure 2-2 is from the 1917 Sanborn Map (Figure 25 in the ACS, 2008 report; also included in Appendix O).

Ore was shipped to the smelter by rail. A 1.5-mile rail spur, known as the Smelter Spur (Figure 2-2), connected Humboldt Smelter to the historic Prescott and Eastern Railroad. This spur went through the current downtown area of Humboldt. Ore was unloaded from an elevated trestle by gravity to the ore concentrator. Mechanical and chemical treatment occurred in the ore concentration area prior to smelting. Processing operations involved physical size reduction and separation processes including crushing, grinding, gravity separation, flotation, and solid-liquid separation (dewatering) (see Section 2.2 for further details). Tailings generated were disposed of onsite in the Smelter Tailings Swale (Figure 2-2).

2.1.3.2 Former Pyrometallurgical Operations Area

The former Pyrometallurgical Operations area encompasses the portion of the Site where the majority of the smelting operations occurred. The smelting process conducted in this area evolved over time but generally involved feeding a combination of high-grade copper ore and concentrates to either a blast furnace to directly produce a matte and waste slag, or alternatively to a roaster for sulfur oxidation followed by reverberatory furnaces to produce a matte and a waste slag. The waste slag was disposed of onsite. The metal- and sulfide-rich matte from either option was subsequently conveyed in molten form to a convertor, where it was refined to produce metallic copper. Convertor slag would have generally been recycled to the reverberatory furnaces to recover additional copper rather than disposed as a waste product.

Five structures currently stand on the property, the most conspicuous of which is a brick flue connected to the smokestack (see Figure 2-2 and Photographs 26 and 27 in Appendix A). The other structures consist of an assay laboratory/office, sawmill, office building, and water tank. All of the buildings are abandoned and in disrepair. In addition to the standing structures, numerous foundations, rubble piles, and remnants of other site activities remain.

In 2013, Lockheed Martin SERAS subcontracted Core Structure Group, LLC to perform a structural condition assessment of the Humboldt Smelter stack (Core Structure Group, LLC, 2013) as part of the ERT Data Gap RI. The rectangular brick flue structure is approximately 140 feet long with a concrete pedestal. The smelter stack is on the southern end of the structure and is approximately 160 feet tall. Significant deterioration was observed throughout the structure. The assessment concluded that the structure is unstable, and total or partial collapse of the structure could occur. The smelter stack is particularly susceptible to collapse due to its height and exposure to wind forces (Core Structure Group, LLC, 2013).

2.1.3.3 Dross Area

After closure and dismantling of the Humboldt Smelter, a large quantity of dross was imported in the late 1950s and early 1960s for reprocessing to recover aluminum and zinc. The dross operations continued until 1970. The zinc dross was a waste material consisting mostly of flue dust and smelter skimmings that was imported from several California die-casting plants, whereas the aluminum dross was shipped from Texas (ACS, 2008) (see Section 2.3.3 for more detail). The dross was stockpiled on the Humboldt Smelter property for processing. Because it is of largely fine and uniform particle size, it is likely that the dross was processed by milling either before it was imported or subsequently at the Site.

The dross area encompasses much of the former Pyrometallurgical Operations area (see Figure 2-2 and Photographs 27 and 28 in Appendix A), and sporadic piles of dross are also present on the Smelter Plateau, with a combined area of approximately 15 acres. The dross area was developed by Lockheed Martin SERAS (2015). EPA observations also indicate that, in the northeastern portion of the primary slag pile (Figure 2-2), dross mixed with loose, crumbling slag extends down to the edge of the Agua Fria River (Photograph 32).

The majority of the dross is relatively homogeneous, white to light gray ash that is easily discernable from the underlying non-dross soil. To the west and south of the smelter stack, however, the dross is heterogeneous mixed with charred wood, metals, black cinder grit, and other debris (Lockheed Martin SERAS, 2015). The dross is fine-grained and is susceptible to wind and stormwater erosion. In 2011, approximately 12 acres of dross (“ash piles”) were sprayed with a fixative agent as an interim remedial action to reduce dispersion (E & E, 2012).

This dross was originally referred to as “smelter ash” in the Initial RI report (EA, 2010). Site records indicate this material is not ash from smelting operations. The historical aerial photograph analysis (see Section 2.3 and Appendix C) shows that the material was not present on the property until the 1950s and early 1960s, after the smelter shut down in 1937.

A retention pond is located to the northwest of the former Pyrometallurgical Operations area and dross areas. The former Humboldt Smelter property boundary crosses through the retention pond (Figure 2-2). During the EA RI field investigation, the retention pond was observed to be dry, and material at the bottom of the pond resembled “ash” or dross (EA, 2010). The retention pond was likely a component of the dross processing operation and was constructed in the late 1950s or early 1960s. This timeframe is supported by the aerial photograph records (see Appendix C).

2.1.3.4 Slag Pile

Smelter slag is a compilation of semi-consolidated and monolithic vitrified material. The slag present on the former Humboldt Smelter property is likely a blast or reverberatory furnace slag. This slag is present on the east side of the former Pyrometallurgical Operations area (primary slag pile) and east of the Smelter Plateau (satellite slag pile), adjacent to and over the banks of the Agua Fria River (see Photographs 29 through 34 in Appendix A). The combined area of the slag piles is approximately 8 acres.

Portions of the slag appear to have been dumped as solidified blocks, some of which have subsequently weathered to gravel or boulder-sized pieces. Other portions of the slag pile appear to have been placed while molten, forming sheets and flows, which later solidified. The slag deposits have formed a steep bluff overhanging the Agua Fria River; slope failures have occurred in some areas (the aerial photograph background on Figure 2-2 illustrates the bluff features). The primary slag pile is covered with cracks, which may be widening with time (Photograph 34 in Appendix A). Current and historical observations indicate that slag extends down to the edge of the Agua Fria River in places along the slag pile (EPA, 2008d; Photographs 29 through 32).

2.1.3.5 Smelter Plateau

The Smelter Plateau is located south of the former Pyrometallurgical Operations area. Precursor mining operations, residential housing during smelting operations, and ancillary smelting and dross operations were present in this area. The Chaparral Gulch Shaft mine was located in the southeastern portion of the Smelter Plateau (see Figure 2-2); this mine provided ore to the Agua Fria Ore Mill and Smelter in the 1870s and 1880s. Residential housing, known as Nob Hill, was built in the early 1900s for smelter managers. Remains of tennis courts, home foundations, and rusted equipment are still present. Sporadic piles of dross and tailings are currently exposed on the plateau, and a second (satellite) slag pile is located along the eastern edge of the plateau, upslope from the Agua Fria River.

2.1.3.6 Smelter Tailings Swale and Floodplain

The Smelter Tailings Swale is a bowl-like formation located topographically lower and west of the Smelter Plateau. The area of the Smelter Tailings Swale is approximately 6 acres. This area was used to store or dispose of tailings that were produced as a waste product from concentrating ore to prepare copper concentrate to feed the smelter. Based on layering and uniform elevation of the apparent original surface, the material was probably piped in as slurry (Lockheed Martin SERAS, 2015). The tailings were stored behind a berm visible across the bottom of the swale (Figure 2-2) that failed, releasing tailings into the Tailings Floodplain. Water erosion in preferential pathways has cut gullies as much as 15 feet deep through the material behind the berm. Photographs 12 through 15 in Appendix A show the Smelter Tailings Swale. The timing of construction of the Smelter Tailings Swale is unclear from the Site record.

Impoundment failures and historical discharges from both the former Iron King Mine and former Humboldt Smelter properties have released tailings into Chaparral Gulch, forming a broad flood plain, called the Tailings Floodplain, that fills the Chaparral Gulch channel. The active channel of Chaparral Gulch continues to run through the floodplain. Photographs 16 through 19 in Appendix A show the Tailings Floodplain. The area of the Tailings Floodplain is approximately 13 acres. The upper few feet of the tailings are unsaturated and oxidized, and range in color from orange to dark red to brown due to abundant iron oxides. Below this depth, the tailings are reduced and saturated; they are gray to dark green to black in color and contain abundant sulfide minerals, including pyrite. The tailings materials are predominantly silt sized and homogenous (Lockheed Martin SERAS, 2015). Efflorescent salts have formed on the surface of portions of the flood plain from repeated evapoconcentration (see Photographs 16, 17, and 19 in Appendix A).

A concrete dam (referred to in this RI Report as the Chaparral Gulch Dam or dam) was built across Chaparral Gulch at the downstream end of the Tailings Floodplain (Figure 2-2) sometime in the early 1900s, although the Site record does not provide a specific construction date. The dimensions of the dam are approximately 26 feet tall, 105 feet wide at the top, and 8 to 12 feet thick at the top. The Chaparral Gulch Dam was constructed to impound tailings and alluvial deposits in Chaparral Gulch and the Tailings Floodplain, and although it restricts groundwater flow in the saturated sediment wedge behind the dam, seepage discharges from the toe of the dam throughout the year, even during the dry season (see Photographs 20 through 22 in Appendix A).

Subsurface deposits characteristic of a tailings pond occur near the base of the unconsolidated deposits upstream of the Chaparral Gulch Dam (Lockheed Martin SERAS, 2015), which suggests the dam may have been used to retain tailings during early operations of the Humboldt and Val Verde Smelters. Although the dam may have been constructed to impound tailings, little or no storage capacity remains behind the dam because of the accumulation of tailings and alluvium, which can now continue to migrate downstream to the Agua Fria River.

2.1.3.7 Lower Chaparral Gulch

Lower Chaparral Gulch is located downstream of the Tailings Floodplain and the dam, in an area where the canyon narrows and deepens. Lower Chaparral Gulch is heavily vegetated (see Photograph 23 in Appendix A), and riparian habitat has developed as a result of a continuous seep of groundwater from the dam. Approximately 800 feet downstream of the Chaparral Gulch Dam and just upstream of the confluence with the Agua Fria River, the Chaparral Gulch channel turns abruptly to the north. There is evidence of high energy and scour conditions at this “elbow,” including large rounded boulders and rocks, and erosional marks on the sides of the canyon and channel deposits. The Lower Chaparral Gulch tailings deposit is located on the north side of Chaparral Gulch at this bend (Figure 2-2 and Photographs 24 and 25). Tailings appear to have been heavily eroded, and efflorescent salts are present within and on top of the deposit. The tailings are likely associated with precursor operations given the proximity to the former Agua Fria Mill Site, or possibly discharges of tailings from upstream operations.

2.1.3.8 Agua Fria Tailings

A tailings pile is located along the Agua Fria River just downslope of the former Chaparral Gulch Shaft. The tailings pile is within the footprint of the “Agua Fria Mill Site” identified on a Sanborn Fire Insurance Map (undated, included in Appendix O) (Figure 2-2). The Chaparral Gulch Shaft mining operation provided ore to the Agua Fria Ore Mill and Smelter in the 1870s and 1880s (ACS, 2008). The Agua Fria Tailings Pile is likely the result of tailings that were tremied or slurried from this predecessor mining and milling operation. The tailings pile occurs at the confluence of a small drainage above a steep near-vertical bank of silt, suggesting that a tailings dam(s) may have been located in the river at the time of operations (see Photograph 37 in Appendix A). A thin layer of tailings is located on top of the silt bank, while the bulk of the remaining tailings deposit is located west of the bank and is heavily eroded.

2.1.4 Surface Water Features and Relationship to Site Contamination

As illustrated on Figure 1-1, three surface water features transect the Site: the Agua Fria River, Chaparral Gulch, and Galena Gulch. Mine and smelter wastes (including tailings, waste rock, and slag) were released, dumped, or placed within these surface water features or in areas that drain to these surface water features, and they have been instrumental in the transport of contamination from the source areas. The following paragraphs provide an overview; these surface water features are discussed in more detail in Section 5.3.

The Agua Fria River is the primary surface water feature in the valley and provides the only true aquatic habitat that occurs within Site boundaries. The Agua Fria River flows from Lonesome Valley south across central Arizona to its confluence with the Gila River near Phoenix. The entire Agua Fria watershed encompasses approximately 2,800 square miles (NRCS, 2007a). The local watershed area within Lonesome Valley is approximately 175 square miles (Nelson, 2012). Near the Site, the Agua Fria River flows south through the eastern portion of the former Humboldt Smelter property in a narrow canyon incised into volcanic and basement rocks. As discussed above, slag deposits have formed a steep bluff overhanging the Agua Fria River in the section adjacent to the Humboldt Smelter property, and a tailings deposit is located along the river near the confluence with Chaparral Gulch. Photographs 29 through 31 and 35 through 38 in Appendix A show the Agua Fria River channel.

The Agua Fria River receives treated wastewater from the Prescott Valley Wastewater Treatment Plant; upstream of the Town of Dewey-Humboldt and State Route 169, the river is categorized as an effluent-dependent water (ADEQ, 2009). An effluent-dependent water is a surface water that, without the point source discharge of wastewater, would be an ephemeral water (would flow only in direct response to precipitation). In the vicinity of the Site, the Agua Fria River is perennial and has designated uses of domestic water source, full body contact (swimming), fish consumption, agricultural irrigation, agricultural livestock watering, and warm water aquatic and wildlife (ADEQ, 2009). No drinking water intakes are known to exist in the Agua Fria River adjacent to the Site or within 15 miles downstream of Chaparral Gulch (ADEQ, 2006).

Chaparral Gulch and Galena Gulch are two intermittent drainages that cut west to east across the Site area. During rain events, these drainages convey surface water runoff to the Agua Fria River. The Chaparral Gulch watershed comprises an area of approximately 9 square miles. The headwaters of the watershed originate within the foothills of the Bradshaw Mountains within the Prescott National Forest. Tributaries to Chaparral Gulch consist of unnamed ephemeral washes (Lockheed Martin SERAS, 2014).

Chaparral Gulch flows southeast through the northern portion of the Iron King Mine site, under State Highway 69, and through the southern portion of the Humboldt Smelter property to the confluence with the Agua Fria River. Chaparral Gulch has been impacted by impoundment failures and historical discharges from both the former Humboldt Smelter property operations and the former Iron King Mine property operations. On the former Humboldt Smelter property, the Chaparral Gulch Dam, which was built across the gulch at some time during the smelter operations, impounded tailings and alluvium and formed the Tailings Floodplain within the gulch channel (Figure 1-3). Photographs 10 and 11 in Appendix A show the section of Chaparral Gulch between State Highway 69 and the Tailings Floodplain. Photograph 18 shows a view within the Tailings Floodplain. Photographs 22 and 23 show lower Chaparral Gulch downstream of the dam. Photographs 24 and 25 show the area in lower Chaparral Gulch where additional tailings have been deposited.

Galena Gulch is a small intermittent tributary to the Agua Fria River. It flows from northwest to southeast and has a total drainage area of approximately 10.4 square miles. Galena Gulch transects the southwestern portion of the former Iron King Mine property adjacent to the former Mineworks area and the former Fertilizer Plant area, and is impacted from these historical operations. Two of the primary shafts (Shafts 1 and 5) and associated waste dumps are located along bedrock benches and adjoining slopes of Galena Gulch in the area south of the former Fertilizer Plant (Figure 2-1) (Lockheed Martin SERAS, 2015). This is the same area where, in 2014, ERT identified waste rock, three abandoned mine shafts, and one small horizontal portal (Figure 2-1; Section 4 of Lockheed Martin SERAS, 2015). Galena Gulch joins the Agua Fria River approximately 1 mile downstream from the former Humboldt Smelter property.

Available references provide different depictions of the location of Galena Gulch. In ADEQ mapping, the drainage running adjacent to the former Iron King Mine property is an unnamed tributary, while the reach identified as Galena Gulch is located to the southwest (ADEQ, 2016). U.S. Geological Survey (USGS) mapping identifies the ADEQ depiction of Galena Gulch as “Ticonderoga Gulch” and labels “Galena Gulch” as further south (USGS, 1975). The USGS mapping also identifies another “California Mine” and “Dredge Tailings” within this southern tributary. The three “Galena Gulch” tributaries are within the same drainage area and intersect upstream of the confluence of the gulch with the Agua Fria River. The tributary adjacent to and crossing the former Iron King Mine property is named Galena Gulch in this RI for consistency with previous EPA Site documents.

More details on hydrology and uses of these surface water features is presented in Section 5.3.

2.2 History of the Town of Dewey-Humboldt

This section provides a history of the Town of Dewey-Humboldt. The Town of Dewey-Humboldt was incorporated in 2004. Humboldt and Dewey represented two distinct communities during the more than 100 years prior to incorporation. The Humboldt area economy was based on mining, whereas the economy of Dewey was based on agriculture and ranching (Town of Dewey-Humboldt, 2014).

2.2.1 Humboldt

Soon after the Arizona Territory was created in 1863, thousands of miners moved into the mountains of central Arizona in search of gold strikes. Prescott, located 12 miles west of the Town of Dewey-Humboldt, was the first permanent settlement in northern Arizona, and continued to be the largest commercial center for the northern region (ACS, 2008).

Precursor operations at the Humboldt Smelter property began in 1876, but substantial activity in the Humboldt area did not occur until the Prescott and Eastern Railroad was built in 1898. The following year (1899), the Val Verde Copper Company was formed to build a large smelter on the Humboldt Smelter property. Val Verde Copper Company built a town they called “Val Verde” north of the smelter works to house the hundreds of employees that were needed to run the smelter. The Val Verde Post Office was established in 1899. The town of Val Verde flourished for just a few years until the smelter was destroyed by fire in 1904 (ACS, 2008).

The Arizona Smelting Company was organized in 1905 to build a new smelter at the location of the destroyed Val Verde Smelter. A new company town, named Humboldt, was built 1 mile west of the Val Verde townsite. Officials formed the Humboldt Improvement Company to develop the new townsite. While some employees lived along Humboldt’s Main Street, many lived in various camps north of the smelter that were known as the Hollow, Cooktown, and Little Mexico. As noted in Section 2.1.3, a small neighborhood for the smelter’s upper managers was located on the Smelter Plateau and was known as Nob Hill (Figure 2-2) (ACS, 2008).

By 1906, a miner’s camp called Blanchard was established just south of the former Iron King Mine property, with a population of about 300. A small company store was built, and the Iron King Post Office was established in 1907. By 1910, the mine was largely inactive and was shut down from 1915 until 1922; many of the company buildings were torn down during this time (ACS, 2008).

After the sudden drop in copper prices following World War I, smelter operations also were cut back considerably and there were times when all smelting activities ceased for several years. Humboldt had a population of about 1,200 in 1918, but by 1920, a quarter of the town’s residents had left. By the 1930s, only a few hundred people still lived in the town. The frame homes on Nob Hill were moved to Prescott and other nearby communities (ACS, 2008).

In 1942, Shattuck Denn Mining Corporation bought the Iron King Mine property. With 220 employees and a payroll of $1.9 million by 1966, Shattuck Denn was the third largest employer in Yavapai County (ACS, 2008). The town of Humboldt remained a very small community, however, as the majority of miners lived 12 miles to the west in Prescott and used the company-sponsored bus service to commute to Iron King Mine. Shattuck Denn closed the Iron King branch of its mining operations in late 1967, and the historic Prescott and Eastern Railroad line, which had been taken over by the Santa Fe Railway, was removed in 1971 (Town of Dewey-Humboldt, 2009).

2.2.2 Dewey

The Dewey area, formerly known as Cherry Siding, was located originally to the north of Humboldt (see “Dewey Proper” on Figure 1-1). Settlers came to this area for ranching and growing crops in addition to mining. Just prior to 1900, there was a hotel, boarding house, saloons, livery stable, and grocery located near the present intersection of State Highways 69 and 169. Fires subsequently destroyed many buildings, requiring the community to rebuild (Town of Dewey-Humboldt, 2009). Farming and ranching continued to be mainstays in the Dewey area. Young's Farm was established in 1946 at the intersection of State Highways 69 and 169 (Town of Dewey-Humboldt, 2009). Young's Farm was a center of activity in Dewey until it was sold in 2006. Mortimer Family Farms now operates at this location and provides seasonal events (Arizona Commerce Authority, 2015). The Agua Fria River watershed land use is still predominantly rangeland. Agricultural lands are currently located west of the Agua Fria River and east of State Highway 69 between Humboldt Proper and Dewey Proper (NRCS, 2007a) (see additional details regarding demographics and land use in Section 5.7).

2.2.3 Combined Recent History

The populations of the Dewey and Humboldt communities declined until the 1950s, when State Highway 69 was paved, Humboldt Elementary School was rebuilt, and the Blue Hills subdivision was developed. These improvements, along with development of other land divisions including the Lazy River Acres subdivision in the 1960s, resulted in population growth through the area despite the closing of the Iron King Mine (Town of Dewey-Humboldt, 2009). The Town of Dewey-Humboldt was incorporated on December 20, 2004. Following incorporation, the Yavapai County Board of Supervisors appointed the Town's first Council and the first Council election was held on September 13, 2005 (Town of Dewey-Humboldt, 2014).

2.3 History of Mining and Smelting Operations

This section provides the operational history at the former Iron King Mine and Humboldt Smelter properties. Unless otherwise noted, information in this section was obtained from the Cultural Resource and Historic Building Survey (ACS, 2008), which is included in Appendix B. Additional information is provided in Appendix O, including plates of the Iron King Mine workings and Sanborn Fire Insurance Maps.

Figures 2-1 and 2-2 show historical features for the former Iron King Mine property and the former Humboldt Smelter property, respectively. Figure 2-3 shows detailed historical features present in the former Pyrometallurgical Operations area on the former Humboldt Smelter property. Figures 2-4 and 2-5 provide an approximate timeline of operations and ownership at the former Iron King Mine property and the former Humboldt Smelter property, respectively. Additional information on specific operational events for the properties is provided in Tables 2-1 and 2-2, respectively. In general, mine and smelter operations fluctuated substantially over time in response to changes in the sale price of the various commodities produced (copper, zinc, lead, gold, and silver).

2.3.1 Relationship between Iron King Mine and Humboldt Smelter Property Operations

Operations began in 1876 at the former Humboldt Smelter property (with milling and smelting local ore for silver), and peak production (primarily smelting copper) occurred from 1899 to 1920. Mining of ore rich in iron, lead, and zinc began in earnest at Iron King Mine in 1906, with a peak production period of 1934 to 1968. The relationship between the two operations is not well understood, but the site record suggests that Iron King Mine did not routinely send ore to any of the former smelting operations at the former Humboldt Smelter property for processing, for the following reasons:

- **Difference in mineral composition.** Ore from the Iron King Mine was rich in lead and zinc and low in copper, while the former Humboldt Smelter property operations processed primarily copper-rich ore. The Iron King Mine deposit was unique, and most mines did not produce lead- and zinc-rich ore even when present, because copper smelters penalized the mines for the presence of zinc as it was considered an impurity in the copper ores (USGS, 1995).

- **Suitability for smelting.** Ore from the Iron King Mine had a high pyrite content, which was problematic for the Humboldt Smelter operations. There was a period in the 1920s and 1930s when Southwest Metals Companies leased both the Iron King Mine and Humboldt Smelter properties. The Southwest Metals general manager used the Iron King Mine as a source of low-grade sulfide ore to use as flux in the smelter's blaster furnace, but the high pyrite content gave unsatisfactory results (ACS, 2008).
- **Peak production periods do not overlap.** Greater than 98 percent of the total production from Iron King Mine occurred from 1938 to 1968. Aerial photographs confirm the Iron King Mine did not start significant operations until the 1940s and 1950s. In contrast, the smelter precursor operations started in the late 1800s; the smelter itself was operating in high gear by 1906 and was in full swing by 1910. The highest production was during World War I. The war ended in 1918 and continuous production at the Humboldt Smelter ended by 1923. Only limited copper smelting operations occurred at Humboldt Smelter after this period. The main smelter was shut down by 1937 (ACS, 2008).

More detail on the specific history of operations at each facility is provided in the following sections.

2.3.2 Former Iron King Mine Property Operational History

The Iron King Mine was an active mine from the late 1890s to 1968, except for a period of shutdown from 1915 to 1922, with production peaking in 1963 (ACS, 2008). The Iron King Mine was located at the northern end of the Big Bug Mining District, which was approximately 5 to 6 miles long and trended south to southwest from Iron King Mine. The district had the lowest copper grade and the highest lead, silver, and gold grades of any other mining district in Arizona (USGS, 1995). Iron King Mine accounted for 99 percent of the ore from this district.

The following sections provide a detailed operational history of the mine, a summary of corroborating and additional findings from an analysis of historical aerial photographs performed by EPA, an evaluation of the possible MTP construction methods, and expected historical water management practices.

2.3.2.1 History of Mining and Fertilizer Plant Operations

J.R. Hagen developed the first mining claim in 1899, after the historic Prescott and Eastern Railroad was built in 1898. The ore was composed primarily of iron sulfide (pyrite) along with zinc and lead sulfide minerals, with lesser amounts of copper, silver, and gold. Iron King Mine was the largest producer of lead and zinc in Arizona at one time. Total production from the Iron King Mine over the entire period of operation was as follows (Table 1 of USGS, 1995):

- 6.3 million tons of ore
- 232 million pounds of lead
- 614 million pounds of zinc
- 13.5 million pounds of copper
- 16.7 million ounces of silver
- 471,000 ounces of gold

The sulfide ore body consisted of three north-northeast trending, echelon lenses that are "down-stepped" to the southeast. The underground mine workings reached a final depth of 3,250 feet below the surface and a horizontal length of 1,600 feet. In addition, 40 miles of shafts, drifts, crosscuts, raises, and winzes have been excavated. The zinc and lead concentrates were shipped offsite for smelting. The milled wastes (tailings) were stockpiled on the mine site, resulting ultimately in the formation of the MTP. During operation, a gold recovery mill was reportedly active and located north of the MTP. It produced tailings that were transported by slurry pipeline to what became the former Small Tailings Pile. Beginning in 1960, the mine tailings from the site have been used to produce fertilizer.

The locations of site features referred to in this section are illustrated on Figures 1-2 and 2-1. Additional details of operations by ownership are presented chronologically below.

American Gold and Copper Consolidated Mining Company (1906 to 1915)

The historic Prescott and Eastern Railroad was built in 1898. The Iron King Spur of the railroad was built in 1904 to serve the mine site. The historical rail alignment near the former Iron King Mine is shown on Figure 1-2. The alignment in the vicinity of, and south of, the Iron King Mine property was derived from the Cultural Resource and Historic Building Survey (ACS, 2008); Site records do not indicate which portions of the alignment correspond to the spur. The American Gold and Copper Consolidated Mining Company started the first large-scale production at Iron King Mine in 1906. Initially, the company concentrated oxide ores taken near the surface and used cyanide leaching to recover small amounts of gold and silver. There was considerable activity at the site for a few years with the mine employing 140 people in 1906. However, by 1910 the mine was largely inactive, and in 1915 it was shut down. For the next 10 years, the Iron King Spur was used sporadically by other mines in the area (ACS, 2008).

Bell, Doht, and Runyan Lease Mine to Southwest Metals Company (1922 to 1934)

By 1922, the New York-based partnership of Bell, Doht, and Runyan owned the mine, which they leased to the Southwest Metals Company, operator of the nearby Humboldt Smelter. There was only sporadic production at the Iron King Mine during the 1920s. It was reported that during this period, low-grade sulfide ore from the mine was used as a flux in the Humboldt blast furnace, but with poor performance (ACS, 2008).

Iron King Mining Company (1934 to 1942)

As new manufacturing technology was developed in the 1930s, demand grew for lead and zinc as important industrial metals. Large-scale production at Iron King Mine was started by Fred Gibbs, a Prescott mining engineer, who purchased the mine in 1934. He found investors to form the Iron King Mining Company in 1937. Iron King Mining Company began shipping oxide ores containing gold, silver, and zinc. The company constructed a mill and flotation system with an initial capacity of 100 tons per day (TPD). Improvements to the processing equipment, including installation of additional new bulk flotation plant and flotation cells, boosted capacity to 250 TPD. In 1939, the Iron King Mine was the largest producer of lead and zinc in Arizona. A cyanide plant was added to treat zinc tailings for additional recovery of gold. By 1941, the mine was producing 1.5 million pounds of zinc and 400,000 pounds of lead, with small amounts of gold and silver as secondary products. By 1942, the mine workings included 25 shafts, some up to 500 feet deep that were sunk 750 feet apart along a 1,500-foot vein.

Shattuck Denn Mining Corporation (1942 to 1968)

In 1942, Iron King Mining Company sold the property to Shattuck Denn Mining Corporation. As the United States had just entered World War II, zinc production for war-related manufacturing was a national priority, and Shattuck made plans for again boosting Iron King Mine's output.

Iron King Mine ore had consistently produced profitable levels of five metals. On average, each ton yielded 0.11 ounce of gold and 4.0 ounces of silver, with lead content at 2.5 percent, zinc at 7.6 percent, and copper at 0.22 percent, in addition to a large concentration of low-grade iron that was marginally useful as smelter flux. Mine work completed prior to 1942 had exposed the upper part of a massive sulfide ore body consisting of narrow veins and lenses ranging from 2 to 14 feet in width and up to 400 feet in length.

Under Shattuck Denn's management, new equipment was installed, including an additional ball mill, classifier, flotation cells, and gravity concentrating tables. Ore was transferred from the mineshaft to the mill by a 24-inch conveyor belt. The ore was first broken down with crushers, and then sent to two ball mills and two classifiers. Zinc sulfate, sodium cyanide, and thiocarbanilide were added to the ground ore and water as reagents in the flotation separation process. The classifier overflow, consisting of 20 percent solids, was pumped to a bank of flotation cells where cresylic acid and xanthate were added.

The resulting lead concentrate was thickened and passed through a disc filter. For processing of zinc concentrates, lead flotation tailings were soaked in a conditioner tank with hydrated lime and copper sulfate and pumped to a bank of flotation cells, and then to flotation machines. The zinc concentrates were dewatered using filtration, then the filter cake was passed over a pan drier. The lead and zinc concentrates were transported by truck to the railroad siding for shipment to smelters in Texas. Additional processing at these plants recovered gold and silver, which provided much of Shattuck Denn's revenue. After numerous plant expansions, by 1950, the Iron King Mine mill processed 200,000 tons of ore for the year, yielding 20,000 ounces of gold, 800,000 ounces of silver, 10 million pounds of lead, and 20 million pounds zinc.

New mining techniques were introduced by Shattuck Denn at Iron King Mine in the 1950s. Previous underground development had been by shrinkage and open stope methods, involving simple removal of ore and waste materials. As the mine was expanded to lower levels, there was concern that sudden caving of mined sections could cause dangerous air blasts, so further mine development started horizontal cut-and-fill stoping, where waste material was returned by conveyor to fill excavated sections. In addition to improving mine safety, the use of conveyors increased mine output from 450 TPD to 700 TPD, and the company eventually boosted production to 1,000 TPD, using flotation and cyanidation of flotation tailings. By the end of the 1950s, the Iron King Mine shipped most of the zinc and lead produced in Arizona, and was the state's largest silver producer and third largest gold producer. In 1959, Shattuck Denn processed 330,000 tons of ore at the site with a mineral content of 35 million pounds of zinc, 12 million pounds of lead, 470,000 pounds of copper, 26,800 ounces of gold, and 863,000 ounces of silver.

By 1962, the ore grade began decreasing when the mine reached 2,400 feet below the surface. Block-caving, a mining technique that allows large production rates by controlled caving, set off a chain of events causing all levels to collapse at the north end of the mine. This resulted in the formation of the Glory Hole at the ground surface.

A new technique of sub-level stoping was adopted in 1963 to extract the lower-grade ore from the deeper levels. This technology utilized a primary tunnel along the strike of the ore body that intersected regularly spaced drives that crosscut the lenses. The crosscuts were driven into stable, competent bedrock and used as haulage-ways to transport the ore to the shafts and hoist ore to the surface. By 1965, this method contributed to a peak output of 333,743 tons for the year, but it also increased the tonnage of waste rock that needed to be stockpiled on the surface.

In March 1964, the large failure of the slope of the MTP occurred during a period of high rain. Only a cursory description of the failure event is available from letters written by the mine manager at the time. The correspondence noted a series of lesser stability problems with the east slope area during a period of 8 to 10 years prior to the failure event (Kentro, 1964). Although the cause of the failure is not well understood, water behind the tailings dam likely resulted in high saturation of the embankment and subsequently created a debris-flow-type failure, likely induced by static liquefaction of the tailings. A significant portion of the tailings slumped and accumulated on Iron King Mine property behind the berm formed by the historic rail bed (Kentro, 1964) west of State Highway 69. This tailings slump formed what is now referred to as the lower MTP (Figure 2-1). Some of the released tailings (likely finer-grain size) were transported east of Highway 69, parallel to the current location of Third Street, and eventually into Chaparral Gulch, which feeds the Agua Fria River to the east. The mine manager provided a very rough estimate that 5,000 tons were transported to the Agua Fria River (Kentro, 1964).

In 1967, there were two main shafts at Iron King Mine, reaching to 2,343 feet and 2,700 feet below the surface. The ore quality declined rapidly with depth, however. At the same time, mining costs were rising while prices for metals were declining, and operations at Iron King Mine were no longer profitable.

In late 1967, the company closed the Iron King Mine. In its last years, the mine had a steady output of 1,050 TPD, producing almost all the lead and zinc mined in Arizona.

In March 1968, the Utah-based partnership of McFarland and Hullinger entered into a lease agreement with Shattuck Denn that allowed them to reopen the Iron King Mine. The maximum output of 600 TPD was just over half of the production rate that Shattuck Denn had achieved. The venture was not profitable, and McFarland and Hullinger closed down their short-lived business at the end of that year.

Fertilizer Plant Operations (1960 to present)

Beginning in 1960, Shattuck Denn operated a small Fertilizer Plant on the southwest portion of the property ("Former Fertilizer Plant" area on Figure 2-1) that produced an iron-based soil supplement extracted from the mill tailings. Iron King Superferrite was marketed by Occidental Chemical Company in western states where alkaline soils required sulfur-based supplements. Fertilizer operations continued after closure of the mine in 1968.

To produce the fertilizer, tailings were fed from bins to a horizontal screw mixer, where concentrated sulfuric acid was added. The resulting chemical reaction converted some of the sulfides to sulfates. After further processing, the wet material was dried in a gas-fired dryer, crushed in a roller crusher, and returned to the mixer, where it was mixed with dry ammonia. The final product was bagged or boxed onsite and shipped to distributors. In 1973, Shattuck Denn began divesting itself of the site. Ironite Products Company bought Shattuck Denn's Superferrite Fertilizer Plant in 1974 and marketed the fertilizer as "Ironite" (ACS, 2008).

A German company, Metex Ltd., acquired rights to some of the tailings at the former Iron King Mine property in 1979 and began evaluating their suitability for reprocessing. The company bought the Ironite fertilizer operations, and developed a process of leaching the tailings, which had high iron and zinc content, with ammonium thiosulfate. This recovered residual gold and silver from the tailings and resulted in a fertilizer and soil supplement. Metex began carrying the Ironite Products Company label in 1987. A $7 million expansion of the plant in 1988 (in the current NAI Operations area) allowed the company to produce up to 200,000 tons of Ironite per year. Ironite was sold in hardware stores until high levels of lead and arsenic were discovered in the product (Maine Environmental Policy Institute, 2002).

Ironite Products Company's ownership of portions of the former Iron King Mine property transferred to NAI in April 2006 (EPA, 2009c). NAI currently owns and operates the MTP and the soil supplement plant to the northeast of the MTP. Tailings are screened, stockpiled, and processed to produce the liquid fertilizer product known as Hydromax (Brown and Caldwell, 2009b).

Recent Operations (2000 to Present)

The former Iron King Mine area is made up of several parcels under different ownership; a few operating industrial businesses remain on the property. Figure 2-6 shows the current land ownership for the former Iron King Mine and adjacent properties.

As discussed above, NAI continues to operate the soil supplement production facility adjacent to and north of the MTP.

In 2001, Kuhles owned the majority of the property to the west and north of the MTP and began operation of the Iron King Waste Reduction and Recycling Facility in the former Glory Hole. The Solid Waste Permit Application stated that this facility would sort wastes, send recyclable materials offsite for further processing, and ship unacceptable materials offsite. The Glory Hole landfill received general waste from the community, including municipal waste, construction debris, and tires until 2005. ADEQ was responsible for the permit to operate this facility, and ultimately revoked the permit and required closure (see additional discussion in Section 3). Dakota Logging, LLC now owns the former Glory Hole (Figure 2-6).

Between 2003 and 2005, Aqua Tec operated a permitted septage treatment facility in the former Fertilizer Plant area. Waste solids from the septage treatment facility were shipped offsite to the Wolf Creek solid waste landfill. Clarified liquids were piped offsite for non-potable uses (ADEQ, 2006).

Iron King Auto Salvage operates an auto dismantling yard adjacent to and south of the MTP. As recent as 2002, a portion of this area was briefly used by PACE Preparatory School, which had an enrollment of approximately 40 students (ADEQ, 2006; EA, 2010).

Current owners of the Iron King Mine property include, but are not limited to, the following (Figure 2-6):

- North American Industries, Inc. (NAI): Owns the MTP and soil supplement production facility adjacent to and north of the MTP ("North American Industries Operations Area" on Figure 2-1).
- Kuhles Capital, LLC or Kuhles Warren C: Owns the majority of the former Mineworks area and the area north of the MTP.
- Dakota Logging, LLC: Current owner of the former Glory Hole and surrounding area.
- Terry L. Nolan Living Trust: Owns the former Fertilizer Plant area.
- State of Arizona: Owns part of the southern MTP and other areas used for mining activities.

2.3.2.2 Summary of Historical Aerial Photograph Analysis

Using photographs taken in 1940, 1953, 1964, 1970, 1973, 1980, 1992, and 2003, EPA prepared a report titled, *Aerial Photographic Analysis of Iron King Mine/Humboldt Smelter Site* (EPA, 2008d; referred to herein as the "aerial photograph report"). This analysis focused on the time period soon after larger-scale mining operations began at the mine. A copy of the aerial photograph report is provided in Appendix C.

The analysis shows that an ore processing facility was observed operating at the time of the first aerial photograph (1940) and was operational through at least 1964. This was the primary ore processing facility at the Iron King Mine and was located in the western central portion of the Site (the former Mineworks area). The size and complexity of the ore processing facility increased considerably from 1940 to 1953 and again in 1964. Based on the aerial photographs, the ore processing facility appeared to have ceased operation by 1970, which is consistent with shut down of the mine in 1968.

The analysis also describes a processing facility (designated PF-1 in the aerial photograph report) located south of the ore processing facility. Based on the aerial photographs, this processing facility was operational in 1940 and continued operation through at least 1980. The purpose of this facility is not clear from the aerial photographs. It was reported that the mill tailings were treated with cyanide for gold recovery (ACS, 2008). This facility may have been initially a component of that process (gold recovery from the cyanide leach solution). The location of PF-1 correlates to the former Fertilizer Plant area shown on Figures 1-2 and 2-1, and in later years of the aerial photographic record (up until 1980), it was likely a component of the production of fertilizer from the tailings.

The analysis also describes an additional processing facility (designated PF-2 in the aerial photograph report) located northeast of the MTP. This facility appears to have been constructed between the 1980 and 1992 aerial photographs, and operation continued through the date of the last aerial photograph in 2003. This facility corresponds to the facility that was built in 1988 by Metex Ltd. to leach the tailings, recover residual gold and silver, and produce a fertilizer and soil supplement. This $7 million construction enabled production of 200,000 tons of Ironite per year. The facility is now operated by NAI and produces Hydromax fertilizer and soil supplements (ACS, 2008).

Based on the aerial photographic analysis, the MTP developed as a series of smaller impoundments within two shallow drainages that were tributaries to Chaparral Gulch. Berms were constructed of tailings in the drainage bottoms to begin the development of perimeter dikes. In 1940, the aerial photograph shows three tailings piles in what is now the northwestern corner of the MTP. By the 1953 photographs, these tailings piles had converged and two larger tailings piles had been developed downstream. In the 1964 aerial photograph, the tailings encompass an area similar in size to the current upper MTP, and a small tailings pond had been constructed within the footprint of what is now the lower bench of the MTP. The 1964 failure of the MTP was visible in the 1970 aerial photograph and resulted in the formation of the lower MTP. After 1970, the MTP did not grow significantly but showed evidence of reworking and regrading.

There is also evidence of potential smaller tailings pond berm failures and outfalls from tailings ponds in the aerial photographs. Outfalls from the smaller tailings impoundments were observed in the 1940 and 1953 photographs as interpreted in the aerial photograph report. Breaches in the berm of the small lower tailings pond were observed in the January 1964 aerial photograph.

The aerial photographs show also that there were other discharges from Iron King Mine to portions of Chaparral Gulch directly to the north of Iron King Mine. These included two impoundments located north of the MTP in a separate tributary to Chaparral Gulch (located close to the main channel of Chaparral Gulch) that were observed initially in 1964 and 1970. These two impoundments were what later became known as the Small Tailings Pile. A breach in the berm of one of the impoundments is evident in the 1973 aerial photograph, and subsequent aerial photographs provide no evidence that surface water from the Small Tailings Pile was contained.

The aerial photographs provide evidence of drainage from the southwest portion of the Iron King Mine site to Galena Gulch. The processing facility PF-1, as well as mine shafts and other ground disturbances, were located adjacent to this drainage and may have been sources of contaminated discharges to Galena Gulch. The operations adjacent to Galena Gulch were relatively small in the 1940 aerial photograph. Operations expanded through the subsequent aerial photographs with a peak level of disturbance in the 1980 photograph, corresponding to the period of fertilizer production in this area.

2.3.2.3 Interpretation of Possible MTP Construction Methods

An interpretation of the MTP construction methods was provided in the Phase 1 Subsurface Exploration Report (GEI, 2012). The interpreted MTP construction methods were identified by GEI from the aerial photograph report (EPA, 2008d) and the results of their geotechnical investigations.

GEI’s analysis concluded that the MTP was constructed using a perimeter dike stacking method in which a slurry of tailings and water was pumped from the mill and discharged along the top of the perimeter pile containment dike, which resulted in raising of the height of the pile. The slurry would have been discharged primarily from low-perimeter dikes located on the eastern perimeter and, to a more limited extent, along the northern and southern perimeter of the MTP. The tailings flow across the ponds was directed using small divider dikes to flow generally east to west and north to south. Coarser-grained fractions settled out close to the discharge point (east and north perimeter) and the finer-grained material settled out progressively further to the west and south. A zone of weaker tailings was found in GEI’s investigation that coincided with the western and southern limits of the tailings ponds in the 1953 and 1964 aerial photographs, which also corresponded the location of the MTP 1964 Blow Out. The decant water was likely returned to the mill for reuse (GEI, 2012).

2.3.2.4 Evaluation of Water Management during Mining Operation

Mineral processing operations at the Iron King Mine required a reliable source of water. Water for the Iron King Mine was supplied in part by pumping from the bottom of Shaft 6 at approximately 30 gpm. This water was slightly alkaline and was not used for domestic purposes. Because the quantity of water pumped from the mine was insufficient for the total requirements of the mine and mill, additional water was supplied from three company-owned wells adjacent to the Agua Fria River. Water from these wells was pumped 2 miles with a 600-foot head gain. The *Mining Methods and Practices at the Iron King Mine* information circular states that the water obtained from the Agua Fria River wells was used for domestic purposes (without specifying whether these were onsite or offsite uses) and for additional mill water (USDI Bureau of Mines, 1950).

Although no specific documentation of water management at Iron King Mine has been found, general milling facility process requirements are known. Water is generally added to the circuit after dry crushing, as the crushed ore is fed to the wet grinding circuit. Water is also needed at other points in the operation. These may have included dilution water prior to flotation, wash water for gravity concentration tables, and slurry pump seal water. Water was likely recycled to some degree, but the tailings ponds consumed water because the tailings are deposited with an elevated moisture content. Hence, the mill and tailings disposal operations would have been a net user of water.

Given the arid climate at Iron King Mine (see Section 5) and the cost for pumping water from the wells along the Agua Fria River, water would have been a valuable resource. Careful management was required, and water recycling would have been employed where convenient.

Even under these conditions of limited water supply, it is likely that operational water discharges would have occurred. Overflow from the tailings ponds would have occurred during periodic large storm events that exceeded the water retention capacity of the ponds. Also, when water quality deteriorates during processing (for example, from buildup of fine particles that settle very slowly, or dissolved constituents that interfere with process chemistry), water may have been discharged rather than recycled. As described previously, outfalls were observed in 1940 and 1953 aerial photographs associated with the tailings ponds (EPA, 2008d). Smaller tailings pond berm breeches were observed in the 1964 aerial photograph.

Because the aerial photographic record begins in 1940, it is not known how tailings were managed during early mining operations. They may have been contained in smaller precursor tailings ponds, or tailings may have potentially been discharged directly to the intermittent drainages.

2.3.3 Former Humboldt Smelter Property Operational History

Beginning in 1876, the former Humboldt Smelter property was the location of at least three smelters and one mine. Following is a detailed operational history of the smelters and mine, and a summary of corroborating and additional findings from an analysis of historical aerial photographs performed by EPA. The locations of site features referred to in this section are illustrated on Figures 1-3, 2-2, and 2-3. Additional details of operations by ownership are presented chronologically below.

2.3.3.1 History of Smelting and Mining Operations

The first smelter (Agua Fria Ore Mill and Smelter) was small and recovered silver from the ores that it processed. The next two smelters (Val Verde Smelter and subsequently the Consolidated Arizona Smelting Company's Humboldt Smelter) were substantially larger and processed primarily copper-rich ore for the production of copper with additional recovery of gold and silver. Ore was transported to the smelter by the Prescott and Eastern Railroad via a 1.5-mile connecting rail spur, known as the Smelter Spur. This spur went through the current downtown area of Humboldt.

The Humboldt Smelter consisted of a concentrating area for ores (which produced copper concentrate and tailings) and a Pyrometallurgical Operations area with a roaster, reverberatory furnaces, a blast furnace, converters, flues, and stacks. There was a power generating station, assay laboratories, fuel oil tanks, and a slag dumping area (adjacent to the Agua Fria River). Finally, there was an extensive system of storage buildings, ore and concentrate conveyors, narrow-gauge rail spurs, and numerous specialized shops. Smelting operations at the Humboldt Smelter ceased in 1937 due to depleted ore reserves and economic conditions (ACS, 2008). After closure and dismantling of the Humboldt Smelter plant, dross was imported for reprocessing to recover aluminum and zinc. Additional details of operations are presented chronologically below.

Agua Fria Ore Mill and Smelter (approximately 1876 to 1884)

The Agua Fria Ore Mill and Smelter was constructed in approximately 1876. It was a water powered stamp mill and smelter with a capacity of 20 TPD. A Sanborn Company Fire Insurance Map (undated, included in Appendix O) depicts an "Agua Fria Mill Site" at the confluence of the Agua Fria River and Chaparral Gulch, overlapping the location of the current Agua Fria Tailings Pile (Figure 2-2). No specific remnants of the mill or smelter are evident. Remains of the mill and smelter may have been destroyed by frequent flooding on the Agua Fria River, which occurred in the early 20th century (ACS, 2008).

Ore was supplied from the Silver Belt Mine, located about 5,500 feet southwest of Iron King Mine, and the Chaparral Gulch Shaft located on the property. The Chaparral Gulch Shaft mine was located in the southeastern portion of the Smelter Plateau (Figure 2-2) and remnants of two filled-in mineshaft depressions are still visible.

The Silver Belt Mine operated from 1870 to 1880. It has been reported that the ore was mainly oxidized and contained much silver and some lead (USGS, 1958).

The Agua Fria Mill and Smelter reportedly produced $350,000 worth of silver during its operating period (ACS, 2008). The ore composition from the Chaparral Gulch Shaft mine has not been identified; however, based on the Agua Fria Mill and Smelter production information, it also may have been a silver-rich ore.

Val Verde Copper Company (1899 to 1904)

The Val Verde Copper Company was formed in 1899 to build a large smelter on the Humboldt Smelter property, due to its proximity to several copper mines and the railroad (ACS, 2008). The Prescott and Eastern Railroad had been built 1 year prior in 1898. The smelter began operation in 1901, with an initial capacity of 250 TPD. The Val Verde Smelter did custom milling and smelting for many small mines in the Big Bug Mining District and other mining districts in the Bradshaw Mountains. The primary ore processed by Val Verde was copper (ACS, 2008). However, ore from the Big Bug Mining District also generally contained economically viable concentrations of lead and zinc (USGS, 1996). It is therefore possible that some lead was produced by the smelter; however, it is assumed that this was a small component of the overall metal production as no production quantities of lead were reported in the Humboldt Smelter records reviewed.

The Val Verde complex included a concentrating plant operated by the Standard Smelting and Refining Company, which ran a battery of crushers that reduced the ore to a fine grit before it was fired in a blast furnace to produce metallic copper. The smelter was destroyed by fire in September 1904. Any remaining foundations of the 1899 Val Verde Smelter were covered during subsequent slag disposal, when molten slag was poured down the slope to the east of the smelter (ACS, 2008).

Arizona Smelting Company and Consolidated Arizona Smelting Company (1905 to 1920)

The Arizona Smelting Company was organized in 1905 to build the new Humboldt Smelter slightly to the northwest of the location where the Val Verde Smelter had been. The smelter was redesigned with equipment upgrades to increase the smelter's copper production. Two large furnaces, a 600-TPD plant for processing copper, and a 500-TPD plant for lead opened in March 1906. The Arizona Smelting Company smelter was apparently the first to successfully use crude oil as the primary fuel for reverberatory type furnaces. The Arizona Exploration Company sought an interest in Arizona Smelting Company, and it was reorganized as the Consolidated Arizona Smelting Company (CASC).

A sudden decline in copper prices resulted in shutdown of the smelter in October 1907. A newly reorganized CASC purchased the property, began rehabilitation of the smelter plant, and resumed operations in 1910. The smelter was again shut down in 1911 for expansion and improvements. In addition to the crushers and classifiers used to reduce the ore, the complex now had a reverberatory furnace, blast furnace, roasting plant, and a flotation mill capable of handling 400 TPD. The new circular roasting furnace and reverberatory furnace were installed in May of 1914 (Engineering and Mining Journal, 1914).

A small neighborhood for the smelter's upper managers, known as Nob Hill, was located on the Humboldt Smelter Plateau, south of the smelter stack. As prevailing winds blew to the north, this area seldom had to contend with the sulfuric fumes from the smokestacks.

The advent of World War I brought great demand for copper. The smelter quickly upgraded equipment to increase production to 1,000 TPD. In its peak production years in 1916 and 1917, CASC produced 30 to 35 tons of blister copper (98 percent pure metallic copper) per day, which with steady operation would produce 2 million pounds of copper bullion per month. From 1915 to 1919, CASC produced a total of 34 million pounds of copper from two company-owned mines: Blue Bell and De Soto mines (ACS, 2008; The Mines Handbook Co., 1922). These mines were located approximately 10 to 15 miles south of the smelter. These two mines were massive sulfide deposits and they produced all the ore that was mined from the Mayer district. The two mines had very similar metal concentrations of copper, gold, and silver. Neither mine produced lead or zinc and both contained only minor amounts of galena and sphalerite (USGS, 1995). By 1918, the smelter was also doing custom work for 67 other mines in the area (ACS, 2008). The Iron King Mine was shut down between 1915 and 1922, so it was not likely to be one of the mines supplying ore to the Humboldt Smelter.

The smelter was equipped with an array of different types of mills, roasters, and furnaces to allow the most effective treatment of each type of ore from the different mines. The highest quality ore required minimal treatment prior to pyrometallurgical smelting. Ore was crushed, ground, and spread on roughing tables where water was used to separate by gravity the silica matrix (tailings) from the copper-bearing minerals (concentrate). This concentrate was then mixed with fuel and fired in a blast furnace to produce metallic (known as blister) copper. In 1917 the smelter operated the blast furnace at a record production of 600 tons of feed per 24 hours (Mining and Scientific Press, 1917).

Ores with lower copper content required greater mechanical and chemical treatment in the ore concentration area prior to smelting. A jaw crusher was used for the first reduction of the ore, which was then passed to a disc crusher. At each stage, the broken ore passed through trommels and screens to return oversize pieces for further crushing before they were delivered to two ball mills. A cone classifier hydraulically separated the coarser particles, which were sent to a pebble mill and then to roughing tables for gravity separation. The finely ground particles were treated with oil in flotation cells, where copper-bearing particles were carried to the tops of the tanks. The resulting concentrate was then roasted to remove the remaining sulfur and smelted in an oil-fired reverberatory furnace, producing a matte. The matte was a semi-metallic copper sulfide, which was conveyed in molten form to the converter to produce metallic (blister) copper.

Tailings were generated as a waste product during ore treatment and concentration, prior to smelting. Tailings were disposed onsite, resulting in the generation of the Humboldt Smelter Tailings Swale and Tailings Floodplain. Both the blast and reverberatory type furnaces produced slag composed of waste metals (for example, iron) and non-metallic minerals (for example, silica). Slag rose to the top of the molten mass in the furnace, and this waste was poured down the steep slope to the east of the smelter. There is evidence of a rail bed on the eastern edge of the smelter for a former narrow-gauge rail that carried the pots of molten slag to the cliff over the Agua Fria River for disposal. All of the pyrometallurgical processes produced hot gases. Some of these gases were captured for production of sulfuric acid, but most were discharged out of tall smokestacks. A series of brick flues carried gases to the stacks.

A detailed description of the smelter circa 1919, and the mines that supported it (Blue Bell and De Soto), was prepared by the Mines Handbook Company (The Mines Handbook Co., 1922). At that time, the capacity of the ore crushing facility was 400 TPD and the flotation circuit capacity was 350 TPD. During 1919, 100,600 tons of ore were treated and 33,600 tons of copper concentrate were produced.

The smelter treated 98,000 tons of feed (concentrate plus unprocessed ore) producing 8.7 million pounds of copper plus 9,400 ounces of gold and 257,000 ounces of silver in 1919. Although the smelter had blast furnaces for both copper (250 ton) and lead (200 ton), no annual lead production data were provided (The Mines Handbook Co., 1918).

When World War I ended in 1918, demand for copper quickly dropped and continued production was no longer profitable. CASC closed the smelter in 1920.

Southwest Metals Company and Charles Dunning (1922 to 1945)

In 1922, the Southwest Metals Company bought the Blue Bell and De Soto mines and leased the Humboldt Smelter from CASC. Production resumed for about 2 years, but the two company mines were nearly depleted by 1924 and the smelter was shut down. The smelter was operated sporadically to serve about 50 other mines in the region until 1927, when much of the equipment was removed. The smelter was refitted in 1929 and was put into operation a few times in the 1930s, but it closed permanently in 1937.

The smelter site was still used for metal processing and other industrial activities in later decades; however, new equipment had to be brought onto the site for each operation. C.H. Dunning acquired a lease on the property in 1942, and throughout World War II, reworked the accumulation of Humboldt Smelter tailings, using flotation cells to extract the remaining copper. The copper concentrates were shipped to the Phelps Dodge smelter at Clarkdale, where some gold and silver were also recovered.

By the time World War II ended, all of the buildings that had been associated with the CASC smelter had been demolished. Only two tall brick smokestacks remained: one of the original 1899 Val Verde Smelter stacks and the large circa 1917 stack of the CASC Smelter. In 1955, the older Val Verde stack was condemned as structurally unsafe and was demolished.

Dross Operations (1958 to 1970)

Several other small-scale industrial businesses occupied the smelter site over the next 20 years. A.L. Poarch set up a plant to treat tailings from the nearby Iron King Mine in 1958 under the name Southwestern Industrial Iron and Chemical Company. He planned to recover sulfur and metals from the tailings using both flotation and smelting. Machinery for a small smelter and fuming plant was delivered but never installed. In addition, zinc dross, a waste material consisting mostly of flue dust and smelter skimmings, was imported from several California die-casting plants for reprocessing. In June 1958, Poarch declared bankruptcy.

H.K. Thomas purchased Poarch’s remaining interest in the property in 1961, which included steel buildings, ore, and 50 tons of zinc dross. Thomas planned to process the dross into metallic zinc. He enlarged a steel building to 3,500 square feet, installed hopper bins, two traveling fire-brick-lined evaporating vats, three pressure digesters, and a small drying kiln. By 1962, Thomas’ Chemical Metallurgical Corporation was using hydrochloric acid to leach zinc from the dross. It also started processing aluminum dross and scrap shipped from Texas. This process involved passing the waste material over a magnetic separator and separation in a jig, grinding it in a ball mill, and separating aluminum particles with a classifier. The resulting concentrate, which had 65 to 70 percent aluminum content, was washed and dried in a kiln. Chemical Metallurgical Corporation, renamed Thomas Enterprises in 1965, maintained these operations with a staff of no more than four people until about 1970.

Recent Operations (1970 to Present)

The Galbraith Lumber Company of Phoenix purchased the 190-acre smelter property in 1970 and operated a sawmill producing wooden pallets until about 1974 (ACS, 2008). Other tenants included an aluminum recycling facility and Humboldt Precast.

Charles and Fay Bagby purchased the former Humboldt Smelter property in 1978. They personally owned the property until 1990, when the property was placed into the Bagby Family Trust. The current owner of the Humboldt Smelter property, Greenfields Enterprises, LLC (Greenfields), purchased the property in 2003 from the Bagby Family Trust (ADEQ, 2006; ADEQ, 2015a). No businesses are currently operating on the property. Figure 2-7 shows the current land ownership for the former Humboldt Smelter and adjacent properties.

2.3.3.2 Summary of Historical Aerial Photograph Analysis

The aerial photograph record of the Humboldt Smelter area begins in 1940. At this time, the smelter had been inactive for several years. The photographs show that access to the Humboldt Smelter was via both East Main Street and a network of rail spurs that enter the Humboldt Smelter from the northwest. The 1940 aerial photograph (as presented in the aerial photograph report [EPA, 2008d]) is the source of the historical rail alignment on the former Humboldt Smelter property shown on Figure 2-2.

There were two general processing areas identified in the aerial photograph report (EPA, 2008d). The “Ore Processing Area-1” (OPA-1) located in the northeastern portion of the site was the location of the primary historical smelter activities and is referred to as the “former Pyrometallurgical Operations area” in this RI. This area was later used for processing of imported material (dross). The dross is a light-colored material; this material was not visible on the property in the 1940 or 1953 historical aerial photographs, but was prevalent in the 1964 and later aerial photographs. Dross processing activity was observed in the 1964 and 1970 aerial photographs and included rail car activity, placement of material at the smelter site, and construction and operation of impoundments. By 1973 it appeared that material processing activities in this area had stopped.

The area described as “Ore Processing Area-2” (OPA-2) is located in the western portion of the Humboldt Smelter site and is referred to as the “Ore Concentration Area” in this RI (see Figure 2-2). This facility did not appear to be operational during the timeframe of the aerial analysis (1940 through 2003). This portion of the site was likely used for processing of ores to recover concentrates that could be fed to the Humboldt Smelter. Tailings from OPA-2 were deposited downslope of the processing area in a small drainage located on the northern side of Chaparral Gulch (referred to as the Smelter Tailings Swale in this RI).

The aerial photographic analysis also provides information on the formation of the Tailings Floodplain within Chaparral Gulch. The extent of vegetative cover can be indicative of the presence or absence of tailings in surficial sediment deposits. Relevant observations from photographic analysis that document changes in vegetation and sediment distribution in Chaparral Gulch include the following:

- In the 1940 aerial photograph, there appeared to be breaches in the Smelter Tailings Swale berm, but the amount of tailings visible below the breaches was relatively small. The concrete dam (Chaparral Gulch Dam) located further downstream on Chaparral Gulch was in place in the 1940 aerial photograph. The portion of Chaparral Gulch above the dam was heavily vegetated with what appears to be a cottonwood/willow riparian forest (WestLand, 2009); however, there was little vegetation observed in the reach of Chaparral Gulch between Third Street and the Smelter Swale.
- In 1953, there appeared to be additional breaches in the tailings dams in the Smelter Swale and the amount of tailings below the Smelter Swale was visibly greater. There was still abundant vegetation in Chaparral Gulch above the concrete dam and little vegetation observed in the reach of Chaparral Gulch upstream of the Smelter Swale.
- In 1964, tailings from the Smelter Swale have migrated further to the southeast (downstream) in Chaparral Gulch. This migration has impinged on the heavily vegetated area above the Chaparral Gulch Dam. A small unvegetated area was also visible a short distance above the dam.

- In 1970, tailings migration from the Smelter Swale did not appear to advance. Vegetation in Chaparral Gulch above the dam appeared to be unchanged. The small unvegetated area above the dam was still visible. A small amount of vegetation was observed in the reach of Chaparral Gulch upstream of the Smelter Swale.
- In 1973, the area impacted by tailings migration from the Smelter Swale appears to have grown. Unvegetated areas above the Chaparral Gulch Dam appeared to have expanded. A small additional amount of vegetation was observed in the reach of Chaparral Gulch upstream of the Smelter Swale.
- In 1980, the unvegetated areas above the Chaparral Gulch Dam had expanded noticeably. The reach of Chaparral Gulch below Third Street and above the Smelter Swale appears to have increased vegetation.
- In 1992, the unvegetated areas above the Chaparral Gulch Dam had expanded. The reach of Chaparral Gulch below Third Street and above the Smelter Swale appeared to have increased vegetation. Little change was observed in the Chaparral Gulch area between the 1992 and the 2003 aerial photographs.

Additional analysis on the formation of the Tailings Floodplain will be presented in Section 8, Contaminant Fate and Transport.

2.4 Summary of Source Areas and Historical Operational Releases

Following is a summary of source materials and historical operational releases at the Iron King Mine and Humboldt Smelter. This history is key to understanding the nature and extent of contamination. Section 7 presents a detailed discussion of the nature and extent of contamination at the Site.

2.4.1 Source Areas

Historical mining and smelting activities resulted in the formation of numerous waste piles. Substantial source areas on the former Iron King Mine property include the following:

- **Main Tailings Pile (MTP).** Approximately 3.5 million yd^3 of milled waste (tailings) were deposited in historical drainages to Chaparral Gulch.
- **Former Small Tailings Pile.** The Small Tailings Pile, located north of the MTP within a drainage tributary to Chaparral Gulch, was a source of contamination to Chaparral Gulch prior to its removal and consolidation within the MTP in 2011.
- **Waste Rock.** Waste rock associated with former mining operations occurs in piles and as a veneer across the former Mineworks area and the former Fertilizer Plant area. Waste rock has also been deposited adjacent to Galena Gulch.

Substantial source areas on the Humboldt Smelter property include:

- **Tailings Swale and Floodplain.** Tailings in the Smelter Tailings Swale were produced as a waste product from concentrating ore to feed the smelter. Impoundment failures and historical discharges from Iron King Mine and Humboldt Smelter released tailings into Chaparral Gulch, forming the Tailings Floodplain.
- **Smelter Slag Material.** The primary smelter slag pile is located along the eastern side of the property, with a smaller satellite pile on the Smelter Plateau to the south. The slag deposits have formed a steep bluff overhanging the Agua Fria River, and slope failures have occurred in some areas.

- **Dross.** Dross was imported after closure and dismantling of the Humboldt Smelter plant for reprocessing to recover aluminum and zinc. The dross is widely spread across much of the former Pyrometallurgical Operations area.
- **Lower Chaparral Gulch and Agua Fria Tailings Deposits.** Tailings deposits are located along Lower Chaparral Gulch, and the Agua Fria River just downslope of the former Chaparral Gulch Shaft, and are likely the result of predecessor mining and milling operations.

2.4.2 Historical Operational Releases

Mining and smelting operations, discussed in detail in Section 2.3, resulted in the release and transport of wastes out of the areas of primary operations.

At the former Iron King Mine, the following historical operational releases are potential sources of contamination to Chaparral Gulch, Galena Gulch, the Agua Fria River, and adjacent properties:

- **MTP Blow Out.** The largest known tailings release event occurred during a slope failure of the MTP in 1964. This MTP Blow Out formed what is now the lower MTP, and tailings were transported under the current location of Highway 69 to Chaparral Gulch and the Agua Fria River.
- **Discharges of Process Water and Tailings Releases.** Routine discharges of process water may have occurred at Iron King Mine, such as overflow from tailings ponds or discharge of poor quality process water that could not be recycled. Tailings pond outfalls and smaller tailings pond berm breeches were observed in historical aerial photographs, indicating that tailings releases may have occurred during storm events prior to the 1964 event (EPA, 2008d). In addition, it is unknown how tailings were managed during very early mining operations. Tailings may have been contained in smaller precursor tailings ponds, or potentially discharged directly to the intermittent drainages.
- **Placement of Mine Waste in Drainages.** Mine waste appears to have been dumped or placed along Galena Gulch, and tailings were deposited adjacent to Chaparral Gulch in the former Small Tailings Pile.

At the former Humboldt Smelter property, the following historical operational releases are potential sources of contamination to Chaparral Gulch, the Agua Fria River, and adjacent properties:

- **Impoundment Failures and Historical Discharges to Chaparral Gulch.** Impoundment failures and historical discharges from both the former Humboldt Smelter property operations and the former Iron King Mine property operations released tailings into Chaparral Gulch, forming the Tailings Floodplain. Breaches in the Smelter Tailings Swale berm were evident in the earliest historical aerial photograph from 1940. In addition, it is unclear when the Smelter Tailings Swale berm and Chaparral Gulch concrete dam were constructed. The Tailings Floodplain upstream of the dam may have been the primary tailings pond for Humboldt (and possibly Val Verde) Smelter during much of its operation.
- **Smelter Stack Emissions.** Particulates discharged from the Humboldt Smelter stack during operations would have been a potential source of metals to adjacent properties.
- **Dumping of Smelter Waste.** There is evidence of a historical narrow-gauge rail on the eastern edge of the smelter that was used to transport pots of molten slag to the cliff over the Agua Fria River for disposal.

At both the former Iron King Mine and the former Humboldt Smelter properties, the following historical operational releases may have occurred:

- **Rail Operations.** The historic Prescott and Eastern Railroad serviced the Iron King Mine, Humboldt Smelter, and Val Verde Smelter. Historical spills and releases likely occurred along the rail line, and the materials could have been subsequently redistributed during redevelopment. A 1.5-mile rail spur, known as the Smelter Spur, connected Humboldt Smelter to the Prescott and Eastern Railroad. This spur goes through the current downtown area of Humboldt Proper and entered the Humboldt Smelter from the northwest (Figure 2-2).

- **Dust Emissions.** Use of heavy equipment; activities such as excavating, blasting, and milling; and loading and transport of materials would have resulted in suspension and migration of fine-grained materials, including tailings and dross.
- **Use of Mine Waste in Construction and Redistribution of Contamination during Development.** Mine waste (such as tailings and waste rock) was historically used as fill and road base in adjacent areas, including some residential areas. In addition, contaminated soil has been redistributed during redevelopment of the area.

SECTION 3

Regulatory Framework, Preliminary Investigations, and Removal Actions

Prior to the start of investigations performed to support the RI, EPA and ADEQ were involved in various inspections, preliminary investigations, and removal actions associated with the Site. These initial investigations were focused on determining compliance with issued permits and regulatory requirements, characterizing the source materials, confirming whether releases of hazardous substances (primarily metals) had occurred, and assessing off-property impacts. The findings of these various efforts formed the basis for inclusion of the combined Iron King Mine – Humboldt Smelter Superfund Site on the NPL in 2008.

This section presents a discussion of the regulatory framework for the Site (Section 3.1), summarizes notable findings of regulatory inspections (Section 3.2), and describes the scope of preliminary investigations (Section 3.3) and removal actions (Section 3.4). Table 3-1 provides a regulatory timeline, including the history of inspections, violations, and enforcement actions at the Site. Table 3-2 provides a summary of the preliminary investigations performed at the Site, prior to listing on the NPL. Table 3-3 provides a summary of removal actions completed for offsite residential and municipal properties and the Small Tailings Pile. See Section 4 for the objectives, methods, and details of investigations performed after the Site was added to the NPL.

3.1 Regulatory Framework

Regulatory involvement at the Site began with EPA and ADEQ inspections associated with stormwater and air quality permit compliance (Table 3-1). Operators at the former Iron King Mine property and the former Humboldt Smelter property have held air quality, stormwater, landfill operation, and wastewater treatment permits, as summarized below. The majority of the information included in this section regarding the regulatory framework was obtained from the 2006 ESI report (ADEQ, 2006) and the 2008 to 2009 Initial RI report (EA, 2010). Permit numbers are provided, where available.

- **Former Iron King Mine Property – Former and Current Fertilizer Operations**
  - Ironite Products Company submitted in 1992 a notice of intent (NOI) for a general stormwater permit under the National Pollutant Discharge Elimination System (NPDES) (ADEQ, 2006). In 1995, EPA issued NPDES Stormwater Permit No. AZR00A425. This permit expired in 1997.
  - Ironite Products Company also operated under an ADEQ air quality permit issued in 1992 (Permit No. 54098-95) and revised in 2006 (Revised Permit No. 31686).
  - In September 2003, ADEQ issued to Ironite Products Company a Multi-Sector General Permit (AZPDES No. AZMSG-8461, Inventory No. 105625), Sector G (Ore Mining and Dressing) for stormwater discharges. Subsequently, Ironite made modifications (such as adding berms to retain stormwater discharges) as a result of EPA and ADEQ inspections between 1995 and 2003 that identified unauthorized stormwater discharge points on the former Iron King Mine property (see Section 3.2).
  - Ownership of the fertilizer operations area and MTP at the former Iron King Mine property transferred from Ironite Products Company to NAI in April 2006. The NAI property is classified as an open mine and is subject to regulation by the U.S. Mine Safety and Health Administration. As of 2009, NAI operates under an ADEQ air quality permit, and the NPDES Multi-Sector General

Permit for Industrial Activities (MSGP-2000) and associated Stormwater Pollution Prevention Plan (SWPPP) (Brown and Caldwell, 2009b).

- **Former Iron King Mine Property – Other Former Operations**
  - Kuhles submitted an application in 2001 for a waste processing facility that would send recyclable materials to recyclers and place construction debris in the former Glory Hole (ADEQ, 2006). ADEQ approved the landfill's Aquifer Protection Permit (APP) in January 2002 (Permit No. 50409700A). Kuhles operated the construction debris landfill in the former Glory Hole from June 2002 through September 2005 (ADEQ, 2006).
  - Aqua Tec operated a permitted septage treatment facility in the former Fertilizer Plant at the former Iron King Mine property between 2003 and 2005. Agua Tec operated the facility under APP No. 105204.
- **Former Humboldt Smelter Property – Former Operations**
  - As of 2006, Greenfields operated at the former Humboldt Smelter under the Multi-Sector General Permit for stormwater (AZPDES No. AZMSG-9907, Inventory No. 105625), Sectors A (Timber Products) and F (Primary Metals), issued March 2004 (ADEQ, 2006).

The regulatory inspections associated with these permits documented unauthorized discharges of stormwater and tailings to surface water bodies and dust emissions at the former Iron King Mine and Humboldt Smelter properties (EA, 2010). The results of the inspections, findings and violations based on the inspections, and enforcement actions are described further in Section 3.2.

In 2001, EPA requested ADEQ gather data from the soil, groundwater, sediment, and surface water as part of a PA/SI. The purpose of a PA/SI is to collect information to assess if a release of hazardous materials had occurred, to determine if additional investigation is required, and to aid decisions regarding the need to place the Site on the NPL. ADEQ completed the PA/SIs of the former Iron King Mine and Humboldt Smelter properties in 2002 and 2004, respectively, and in 2006, ADEQ completed an ESI of both properties (these are described further in Section 3.3).

In 2003, Ironite Products Company, then owner of a portion of the former Iron King Mine property, joined ADEQ's Voluntary Remediation Program (VRP).

In 2005, ADEQ requested EPA to conduct a removal assessment to identify off-property impacts to surface soil at residential properties downslope of the Iron King Mine property along Chaparral Gulch. The findings of the removal assessment formed the basis for the *Administrative Settlement Agreement and Order on Consent for Removal Action* (Settlement Agreement) between EPA and Ironite Products Company (EPA, 2006a). The Settlement Agreement required Ironite Products Company to perform a soil removal action at four residential properties along Chaparral Gulch that had been impacted by contamination associated with the former Iron King Mine operations.

EPA evaluated the information gathered during the PA/SI and ESI using EPA's Hazard Ranking System (HRS). The HRS is the primary method of determining a site's eligibility for placement on the NPL. EPA determined that the Site was eligible for inclusion on the NPL based on the findings of these investigations. In June 2007, EPA requested Arizona Governor Napolitano's concurrence to place the Site on the NPL. In September 2007, Arizona Governor Napolitano consented. On March 19, 2008, EPA formerly proposed the Site for inclusion on the NPL and received public comments on this action. On September 3, 2008, the Site was formally placed on the NPL (Federal Register, 2008). Remedial investigations began in 2008 (refer to Section 4).

3.2 Regulatory Inspections, Violations, and Enforcement Actions

Inspections performed by EPA and ADEQ associated with the various permits issued for site operations documented unauthorized releases of stormwater and tailings to tributaries of Chaparral and Galena Gulches at the former Iron King Mine property and similar releases to Chaparral Gulch at the former Humboldt Smelter property. In addition, agency inspection reports, notices of violation (NOVs), and community complaints also documented excessive dust emissions from both properties. The following sections summarize notable findings for each property (see also Table 3-1).

3.2.1 Former Iron King Mine Property

This section describes regulatory inspections, violations, and enforcement actions related to former and current operations at the former Iron King Mine property.

3.2.1.1 Fertilizer Operations

The following summary is related to the Ironite Products Company and NAI fertilizer operations in the eastern portion of the former Iron King Mine property (ADEQ, 2006; EA, 2010; Brown and Caldwell, 2009a). Fertilizer operations moved from the former Fertilizer Plant to the NAI Operations Area (as referred to in this RI) in 1988.

- ADEQ issued air quality permit violations to Ironite Products Company in 1995, 2006, and 2007 (Table 3-1). In addition, in 1997 ADEQ received numerous complaints from the local community for dust emissions during construction at the mine site (EA, 2010).
- NPDES Stormwater Permit No. AZR00A425 authorized Ironite Products Company to discharge stormwater from the Ironite plant site (termed the “NAI Operations area” in this RI) but not from tailings piles. In 1995, EPA performed an inspection of the facility to evaluate compliance with this permit. The following were significant inspection findings:
  - EPA personnel observed that runoff from the north side of the MTP would flow into a retention pond designated 40-01A; overflow from this retention pond would then flow into a retention pond designated 40-02A (Figure 2-1), and discharge from that pond would flow through a culvert to a drainage channel that enters Chaparral Gulch (EA, 2010). Both ponds contained tailings. Discharge from pond 40-02A into the Chaparral Gulch was not permitted.
  - EPA also noticed that retention pond 200-5S (Figure 2-1) was collecting runoff from the MTP (EA, 2010). Drainage from this pond could then discharge into a culvert beneath the plant entrance road and into another culvert along State Highway 69. Although retention pond 200-5S was dry, EPA observed liquid flowing from the culvert beneath the plant entrance road. EPA observed this water flowing beneath Highway 69, via a culvert, and into Chaparral Gulch. ADEQ collected samples of this liquid, which appeared to be natural groundwater flow or discharge from the tailings (ADEQ, 2006).
- During stormwater inspections of the Ironite Products Company operations in 1998 and 2002, ADEQ personnel observed that the unauthorized culverts observed in 1995 by EPA leading from retention ponds 40-02A and 200-5S (Figure 2-1) had not yet been closed, and therefore discharge to Chaparral Gulch was still possible. In 2005, Ironite Products Company claimed the culvert had been closed.
- During stormwater inspections of Ironite Products Company operations performed in 2003, ADEQ personnel observed additional unauthorized releases to surface water bodies (Table 3-1). ADEQ issued Ironite Products Company violations for unauthorized discharge of runoff from tailings and settling ponds (40-02A and 200-5S, described above; Figure 2-1) into an unnamed wash that was a

tributary to Chaparral Gulch. Apparently, the discharge had a substantial sediment load because it formed a bank deposit in the tributary (also a violation).

- In 2006, NAI documented that facility modifications had been made in response to ADEQ's request to update stormwater Best Management Practices (BMPs). The NAI SWPPP stated that, following these modifications, the entire "site" (i.e., the NAI Operations area and MTP) was bermed or graded so that all runoff would remain on the property (Brown and Caldwell, 2009a). Facility modifications included the following (Brown and Caldwell, 2009a and 2009b) (additional details on BMPs are described in the SWPPP):
    - Removal of exposed tailings along the east side of Old Iron King Road
    - Removal of culverts that had potential to discharge stormwater from the NAI Operations
    - Increasing the capacity of some of the stormwater retention ponds
    - Construction of berms to divert stormwater runoff and contain runoff within onsite retention ponds
    - Placement of straw bales to stabilize erosion rills
    - Development of procedures for dredging, pumping excess water, and other maintenance of Retention Pond 200-5S

3.2.1.2 Other Operations

The following inspection findings and violations relate to Aqua Tec's operation of the permitted septage facility located in the former Fertilizer Plant area at the former Iron King Mine property:

- In 2005, ADEQ performed a site inspection (EA, 2010). ADEQ personnel observed sludge, sewage, and stormwater from the facility entering a wash alongside the facility, resulting in a violation of the facility's APP.
- Aqua Tec ceased operations in 2005, drained the septage tanks, and constructed a containment berm to complete corrective actions.

The following inspection findings and violations relate to the Kuhles property (including the former Mineworks area and north of the MTP). Many of these are associated with operation of the former Glory Hole landfill (Table 3-1).

- During inspections of the Kuhles property in 1998 and 2001, ADEQ personnel observed the following (ADEQ, 2002; EA, 2010):
    - In 1998, two piles of drums that may have contained cyanide were situated on a pile of waste rock north of the former Glory Hole. These drums were not reported in 2001, although state personnel noted that the waste rock pile where the drums had been stored was stained.
    - Extensive white stains were observed around the former Iron King Mine mill (Figure 2-1). Stains also were observed around the former assay laboratory, the east side of the former mechanical room, and near mineshaft numbers 6 and 7 (Figure 2-1). In addition, a gray berm was observed along the boundary of the former Mineworks area and the MTP. State personnel also noted a wash flowing from north to south on the west side of the former Mineworks area.
    - In 1998, small containers that appeared to contain laboratory chemical waste were on the ground near the former assay laboratory. Subsequent documentation indicated that laboratory wastes had been stockpiled, graded, and spread out over an area 250 feet wide by 100 feet long; this stockpile was not observed during the 2001 ADEQ site inspection.

- In 2003, ADEQ issued Kuhles a violation for unpermitted stormwater releases to a tributary (unnamed wash) of Galena Gulch.
- In 2005, ADEQ issued an air quality violation for inadequate cover on the Glory Hole landfill and windblown litter.
- Also in 2005, ADEQ observed unacceptable waste items in the landfill including municipal waste and tires; violations resulted in a compliance order.
- In 2008, ADEQ issued Abatement Order A-19-08 for improper demolition of asbestos-containing structures.
- In 2009, the ADEQ filed a lawsuit for improper demolition of structures containing asbestos and disposal of asbestos in the Glory Hole landfill.
- In November 2009, Maricopa County Superior Court ordered Kuhles to comply with ADEQ's abatement order.
- In 2010, ADEQ issued a revised APP for the landfill to allow for construction of a final cover, complete other closure activities, and require post-closure monitoring.

3.2.2 Former Humboldt Smelter Property

In 2004, ADEQ issued violations to Greenfields, current owner of the former Humboldt Smelter property, for unauthorized discharge of tailings and stormwater to Chaparral Gulch, as evidenced by erosional features observed in exposed tailings and deposition of a bank feature in Chaparral Gulch, and for discharge of stormwater without a permit (EA, 2010). The violations required Greenfields to remove the tailings from Chaparral Gulch, to file an NOI seeking coverage under the Multi-Sector General Permit for stormwater, and to prepare a site-specific SWPPP.

In 2007, ADEQ issued to Greenfields a violation of air quality regulations for failure to prevent excessive amounts of particulate matter (dust) from becoming airborne from fly ash piles (EA, 2010). The material becoming airborne was likely imported dross, which has a gray ash-like appearance (fly ash is not known to have been generated at the Site).

3.3 Preliminary Investigations

Prior to inclusion of the Site on the NPL, ADEQ and EPA conducted several investigations at the former Iron King Mine and Humboldt Smelter properties to assess site conditions and evaluate whether the Site should be added to the NPL. Table 3-2 summarizes the scope and findings of the pre-NPL investigations.

These previous investigations included:

- 2002 PA/SI of the former Iron King Mine property (ADEQ, 2002)
- 2004 PA/SI of the former Humboldt Smelter property (ADEQ, 2004)
- 2005 EPA Removal Assessment for residential properties near the former Iron King Mine (E & E, 2005)
- 2006 ESI of the former Iron King Mine and former Humboldt Smelter properties (ADEQ, 2006)
- 2008 Ironite Products Company/NAI sampling (Brown and Caldwell, 2009b) (performed under ADEQ's VRP)

In addition, environmental consultants performed several environmental site assessments for property owners or prospective owners at the former Iron King Mine and former Humboldt Smelter properties between 1998 and 2003 (see Table 3-2). AGRA Earth & Environmental performed a Phase I site assessment of the former Iron King Mine property for a real estate mortgage lender in 1998 (AGRA, 1998).

Hoque & Associates performed a Phase I site assessment at the former Humboldt Smelter property in 2002 for Kuhles (Hoque & Associates, 2002). Hoque & Associates also performed a Phase II site assessment for the former Humboldt Smelter property for Kuhles Konstruction, Inc. in 2003 (Hoque & Associates, 2003).

The following sections further describe the investigations performed by ADEQ and EPA. Figures 3-1 through 3-4 show the locations of the associated soil (Figures 3-1A and 3-1B), sediment (Figure 3-2), surface water (Figure 3-3), and groundwater samples (Figure 3-4). Figure 3-1A shows all soil sample locations but with labels included only for the samples collected on the former Humboldt Smelter property and off-property locations. Figure 3-1B is a closer view with labels for soil samples collected on the former Iron King Mine property.

The data collected during the ADEQ and EPA investigations were incorporated, to the extent feasible, into the dataset used for this RI. Data without sample coordinates, locations within a subsequent removal action extent, and data flagged as rejected due to quality issues were excluded from the RI dataset. As discussed further in Section 6.1, the Site database (see Appendix G) contains over 200,000 analytical data records, in addition to the field and lithologic datasets, collected over 12 years (from 2002 to 2014) during the pre-NPL investigations and RIs. The data included in the Site database and used for the RI are of suitable quality to assess the nature and extent of site contamination and baseline human health and ecological risks, and to make reliable risk management decisions for the Site.

3.3.1 2002 PA/SI of the Former Iron King Mine Property, Arizona Department of Environmental Quality (ADEQ, 2002).

ADEQ completed the PA/SI of the former Iron King Mine property in 2002 (ADEQ, 2002). ADEQ collected and analyzed samples of surface and subsurface soil, sediment, surface water, and groundwater (see Figures 3-1A/3-1B, 3-2, 3-3 and 3-4 for locations of these samples). Soil samples were analyzed for metals, cyanide, volatile organic compounds (VOCs), and semivolatile organic compounds (SVOCs); surface water and sediment samples were analyzed for metals and cyanide; and groundwater samples were analyzed for metals, cyanide, VOCs, SVOCs, and anions. SVOCs and VOCs were detected infrequently in soil and groundwater. The following discussion focuses on metals, particularly arsenic and lead, which occurred at elevated concentrations in the sampled media.

ADEQ used the following criteria to determine if a release had occurred: (1) the hazardous substance was attributable to the Site; (2) the analyte concentration was greater than or equal to the appropriate detection limit; and (3) the analyte concentration exceeded background concentrations (ADEQ, 2002). In accordance with standard practice for PA/SI release evaluations, for constituents that had a background concentration greater than or equal to the detection limit, an analyte concentration of at least three times the background concentration was considered by ADEQ to be indicative of a release. To establish background concentrations, ADEQ collected several samples for each media from areas that were not expected to have been impacted by the Site. While useful for the purpose of the PA/SI, the background concentrations used in the PA/SI are not statistically defensible background levels, in part because they were based on results for only a few samples. Section 6.2 discusses the approach used to establish background concentrations for metals in soil for this RI, which included soil data collected as part of Site investigations performed between 2002 and 2013.

ADEQ also compared the soil analytical results to regulatory benchmark levels (for example, EPA Region 9 Preliminary Remediation Goals [PRGs] and Arizona Soil Remediation Levels).

The following subsections discuss results associated with each media.

3.3.1.1 Surface and Subsurface Soil

ADEQ collected soil samples at 21 locations (shown on Figures 3-1A and 3-1B). The on-property samples were located in potential source areas, including the MTP (sample locations IK-S1, IK-S2, and IK-S4), Glory Hole (IK-S23), retention ponds (IK-S20, IK-S21, and IK-S22), former assay laboratory building (IK-S9 and IK-S11), former assay laboratory waste dump (IK-S25), waste rock in the former Mineworks area and former Fertilizer Plant area (IK-S8 and IK-S19), a berm along the border of the former Mineworks area and MTP (IK-S18), and the Ironite (now NAI) Operations area (IK-S27). ADEQ also collected samples from perceived background areas (IK-16 and IK-17) and at the former PACE Preparatory Academy schoolyard (which briefly operated in the area of the auto recycling facility south the Iron King Mine, location IK-S24).

Soil samples were collected at depths of 0.5 to 1 foot below ground surface (bgs) (10 samples), 1 to 2 feet bgs (15 samples), and 5 to 7 feet bgs (9 samples). The metals results, including arsenic and lead, exceeded release criteria at the MTP, waste rock piles, assay laboratory waste dump, Glory Hole, other areas at the mine site, and the PACE Preparatory Academy schoolyard. ADEQ's report indicates metals concentrations also exceeded regulatory benchmark levels. The maximum arsenic concentration, 7,600 milligrams per kilogram (mg/kg), was detected in a sample collected from the MTP (location IK-S4). The maximum lead concentration, 14,200 mg/kg, was detected in a sample collected from the former assay laboratory waste dump (location IK-S25). The results greatly exceeded those of the ADEQ background samples (17 to 28 mg/kg arsenic, and 2.3 to 226 mg/kg lead).

ADEQ concluded a release of metals had occurred to soil, and that metals concentrations exceeded regulatory benchmark levels.

3.3.1.2 Sediment

ADEQ collected sediment samples at 10 locations, including 5 locations in Chaparral Gulch, 2 locations in Galena Gulch, and 2 locations in the Agua Fria River near its confluence with Chaparral Gulch. One sediment sample was also collected in the drainage ditch between retention pond 200-5S and State Highway 69. Two samples (IK-D1 in Galena Gulch and IK-D2 in Chaparral Gulch) were considered by ADEQ to be background samples. Figure 3-2 shows the sample locations.

The metals concentrations in the background samples from Galena and Chaparral Gulch (IK-D1 and IK-D2, respectively) were substantially lower than samples collected from downstream areas. For example, 11 mg/kg lead was detected in the background sample in Galena Gulch (IK-D1), and 454 mg/kg lead was detected the sample collected in Galena Gulch downstream of the former Mineworks area (IK-D4). The difference in metals concentrations between the background and downstream locations was also substantial in the Chaparral Gulch samples (8.9 mg/kg lead in IK-D2 versus 339 mg/kg lead in the downstream location IK-D12).

The highest arsenic and lead concentrations (888 and 777 mg/kg, respectively) were detected in sample IK-D7, which was collected in the drainage ditch between pond 200-5S and State Highway 69. From 1995 through 2003, EPA and ADEQ noted unauthorized discharge of runoff from tailings and settling ponds (40-02A and 200-5S, Figure 2-1) into an unnamed wash that was a tributary to Chaparral Gulch (Section 3.2.1). The elevated metals concentrations may have been caused by erosion and transport of tailings from the MTP.

Metals concentrations collected within the Agua Fria River upstream of the confluence with Chaparral Gulch (IK-D3) (14 mg/kg arsenic and 36 mg/kg lead) were similar to (and actually greater than) concentrations downstream of the confluence with Chaparral Gulch (IK-D20) (9 mg/kg arsenic and 6 mg/kg lead).

ADEQ concluded a release of metals had occurred to sediments of Chaparral Gulch and Galena Gulch, and that metals concentrations in these surface water features exceeded regulatory benchmark levels.

3.3.1.3 Surface Water

ADEQ collected surface water samples from the Agua Fria River at three locations: (1) IK-W3 located approximately 300 feet upstream of the confluence with Chaparral Gulch; (2) IK-W30 located immediately downstream of the confluence; and (3) IK-W20 located approximately 100 feet downstream of the confluence. Figure 3-3 shows the sample locations.

The total manganese and iron concentrations in samples collected at or downstream of the confluence with Chaparral Gulch (40 to 100 micrograms per liter [µg/L] iron and 30 µg/L manganese) were greater than the concentration upstream of the confluence (13 µg/L iron and 2 µg/L manganese).

ADEQ concluded a release of manganese and iron had occurred to the Agua Fria River, as documented in samples collected at its confluence with Chaparral Gulch and downstream of Chaparral Gulch. However, at the time of the 2002 PA/SI, data were not sufficient to attribute the elevated levels of manganese in surface water to the Site.

3.3.1.4 Groundwater

To characterize groundwater conditions, ADEQ collected groundwater samples from three locations: (1) a background well (GW-586482); (2) the old Ironite Products Company production well (GW-551459); and (3) the Humboldt Elementary School well (GW-576555). Figure 3-4 shows the well locations.

The arsenic concentration (22.5 µg/L) in the Ironite Products Company production well exceeded release criteria but did not exceed the maximum contaminant level (MCL) promulgated at the time of sampling (50 µg/L) (the arsenic MCL is now 10 µg/L). Zinc concentrations in the Ironite Products Company production well (0.045 milligrams per liter [mg/L]) and the Humboldt Elementary School well (2.37 mg/L) exceeded release criteria but were below EPA benchmarks and regulatory standards. The concentration of nitrate in the Humboldt Elementary School well (12 mg/L) exceeded release criteria and the MCL of 10 mg/L.

3.3.1.5 Delineation of Source Areas

Based on the samples collected, ADEQ identified the following hazardous substance source areas, defined as areas were a hazardous substance has been deposited, stored, disposed, or placed, as well as areas that have become contaminated from migration of a hazardous substance:

- MTP
- Retention ponds and sediments adjacent to the MTP
- Waste rock and stained soil in the former Mineworks and former Fertilizer Plant areas
- Assay laboratory waste dump
- Berm that separates the Ironite Products Company and Kuhles properties
- Former Glory Hole
- PACE Preparatory Academy schoolyard
- Sediments in Galena Gulch
- Sediments in Chaparral Gulch

3.3.2 2004 PA/SI of the Former Humboldt Smelter Property, Arizona Department of Environmental Quality (ADEQ, 2004)

ADEQ completed the PA/SI of the former Humboldt Smelter property in 2004 (ADEQ, 2004). For this investigation, ADEQ collected and analyzed samples of surface soil, sediment, and surface water. ADEQ used the same approach described above for the former Iron King Mine property PA/SI to determine if a release had occurred. The samples were analyzed for metals, cyanide, SVOCs, and anions. The following discussion focuses on metals, particularly arsenic and lead, which occurred at elevated concentrations in the sampled media.

3.3.2.1 Surface Soil

ADEQ collected surficial samples of mine waste or soil from the following potential source area locations: (1) former ore concentration area (location HS-01); (2) retention pond (HS-23); (3) dross piles (HS-05 and HS-06); (6) areas near the former assay laboratory (Figure 2-3) (HS-04, HS-07, HS-08, and HS-09); (4) the Smelter Tailings Swale (HS-12, HS-13, and HS-14); and (5) Tailings Floodplain just above the Chaparral Gulch Dam (HS-16). ADEQ also collected surface soil samples from the Humboldt Elementary School (HS-34 and HS-35), one residential property east of the smelter (HS-42), one residential property northwest of the smelter (HS-43), and a background location in undeveloped property upwind (south) of the smelter (HS-47). Figure 3-1A shows the surficial soil sample locations.

All of the samples were collected at 0.5 foot bgs. The maximum arsenic and lead concentrations (1,100 mg/kg and 2,880 mg/kg) were detected in samples from the ore concentration area (HS-01) and dross area (HS-05), respectively. The concentration of arsenic, lead, copper, zinc, and/or other metals exceeded release criteria in source area samples, including the Smelter Tailings Swale, Tailings Floodplain, former ore concentration area, retention pond, dross pile, and former assay laboratory area.

In addition, lead and zinc concentrations were higher in samples collected from the Humboldt Elementary School than in background samples collected by ADEQ (for example, 68 mg/kg lead vs. 15 mg/kg lead). The lead and zinc concentrations in the sample HS-43 collected at the residence northwest of the former Humboldt Smelter property (543 mg/kg and 1,110 mg/kg, respectively) also exceeded the concentrations in the background samples collected by ADEQ. This property is located between Main Street and Sweet Pea Lane, near the area of the 2011 removal assessment and TCRA (Section 3.4.2).

3.3.2.2 Sediment

ADEQ collected sediment samples from three locations: (1) in Chaparral Gulch on the downstream side of the Tailings Floodplain dam (HS-38); (2) in the Agua Fria River adjacent to the primary slag pile (HS-39); and (3) in the Agua Fria River upstream of the former Humboldt Smelter property (HS-41). Figure 3-2 shows the sample locations.

Arsenic, lead, and zinc concentrations detected in the sample from Chaparral Gulch (HS-38) (2,320 mg/kg, 89, mg/kg, and 1,880 mg/kg, respectively) were significantly higher than concentrations in the sample from the upstream Agua Fria River location (HS-41) (13 mg/kg, 9.5 mg/kg, and 45 mg/kg, respectively). The reported metals concentrations detected in the sediment sample adjacent to the slag pile in the Agua Fria River (HS-39) was similar to the sample upstream of the Humboldt Smelter property.

3.3.2.3 Surface Water

ADEQ collected surface water samples from three locations: (1) lower Chaparral Gulch (downstream of the Tailings Floodplain and Chaparral Gulch Dam) (HS-38); (2) the Agua Fria River adjacent to the primary slag pile (HS-39); and (3) a background location upstream of the former Humboldt Smelter property (HS-41). These surface water samples were collocated with the sediment samples described above. Figure 3-3 shows the sample locations.

Arsenic, iron, manganese, zinc, and other total metals concentrations in the sample collected from Chaparral Gulch (HS-38) significantly exceeded the concentrations in the sample collected at the background location (HS-41) (for example, total arsenic was 214 µg/L in the lower Chaparral Gulch sample vs. 2.4 µg/L arsenic in the background sample). The arsenic concentration in the sample collected from the Agua Fria River adjacent to the slag pile (HS-39) was 15 µg/L; however, this result was reported as nondetect. The sample concentrations in lower Chaparral Gulch exceeded the release criteria for surface water.

3.3.2.4 Delineation of Source Areas

The following conclusions were included in the 2004 PA/SI (ADEQ, 2004 2006):

- Arsenic, lead, copper, zinc, and/or other metals exceeded release criteria in source area samples, including the Smelter Tailings Swale, Tailings Floodplain, former ore concentration area, retention pond, dross pile, and former assay laboratory area.
- Lead and zinc were elevated in soil at the Humboldt Elementary School and the residence to the northwest of the former Humboldt Smelter in comparison to background samples.
- Surface water and sediment samples indicated that arsenic met the criteria of an observed release in lower Chaparral Gulch.

3.3.3 2005 EPA Removal Assessment (E & E, 2005)

In 2005, ADEQ requested that EPA assess surface soils at residential properties in the vicinity of Chaparral Gulch downstream from the former Iron King Mine property. In response to that request, EPA conducted a site assessment of 17 properties along Chaparral Gulch adjacent to, or downstream of, the former Iron King Mine property (E & E, 2005). The objective of the investigation was to characterize arsenic and lead concentrations in soils at 16 privately owned residential properties and a horse pasture along Chaparral Gulch that may have been impacted by erosion of tailings from the former Iron King Mine property. EPA also collected samples at properties north and south of the investigation area considered to be representative of background conditions and bias samples from residential areas within a ¼-mile radius of the former Humboldt Smelter property.

For this investigation, EPA collected nine surface samples (0 to 0.5 foot bgs) and one subsurface sample (1.5 feet bgs) at each of the 17 residential properties and analyzed the samples for arsenic and lead. Figure 3-1A shows the locations of the sampled properties. Coordinates for most of the samples collected within the residential properties are not available; for these locations, the property outlines are shown on Figure 3-1A.

Background samples were collected from nine locations; these locations are designated “BG” on Figure 3-1A. Bias samples were collected from eight locations; these locations are designated “S” on Figure 3-1A. Data from the 2005 EPA Removal Assessment (E & E, 2005) are included in the Site database for locations where coordinates are available.

EPA averaged the arsenic and lead concentrations detected at each residential property, and then compared those average concentrations to the average concentrations of the background samples (31 mg/kg arsenic and 20 mg/kg lead) and to EPA Region 9 PRGs (22 mg/kg arsenic and 400 mg/kg lead). Subsequent analysis of sitewide background concentrations supersedes the background concentrations used for this 2005 Removal Assessment. Section 6.2 discusses the approach used for this RI to establish background concentrations for metals in soil.

EPA used the non-parametric Mann-Whitney test to determine if the average metal concentration for a property was greater than the average of the background samples used for the study or PRGs. The average arsenic concentrations ranged from 28 mg/kg to 115 mg/kg, and the average lead concentrations ranged from 24 mg/kg to 170 mg/kg. The average arsenic concentration for six properties was statistically greater than the background values used for the study. There was no statistically significant difference between the lead concentrations for the sampled properties and the background value used for the study.

EPA concluded that average arsenic concentrations in samples from four properties were substantially higher than the other properties; these properties are designated as O02, O03, 171/O04, and O07C on Figure 3-5, which shows all of the removal action areas performed to date. EPA concluded that these properties were impacted by contamination from the former Iron King Mine property, with average arsenic concentrations ranging from 80 to 115 mg/kg. These results formed the basis for the Settlement Agreement (EPA, 2006a) between EPA and Ironite Products Company, which required Ironite Products Company to excavate the contaminated soil at these properties. Ironite Products Company began the removal action under EPA's oversight in July 2006. Section 3.4.1 provides the detailed scope of this removal action.

3.3.4 2006 Expanded Site Investigation, Arizona Department of Environmental Quality (ADEQ, 2006)

In 2006, ADEQ prepared an ESI of the former Iron King Mine and Humboldt Smelter properties at the request of EPA (ADEQ, 2006). The ESI combined the findings of the previous PA/SIs for the former Iron King Mine and the former Humboldt Smelter properties with the results of additional groundwater sampling. The purpose of the study was to provide data to support the HRS for the combined Site and to evaluate the extent of groundwater contamination.

In January and February 2006, ADEQ collected groundwater samples from two Humboldt Water System Municipal Wells, nine domestic wells near the former Iron King Mine and Humboldt Smelter properties, and one well located approximately 1.5 miles north of the former Humboldt Smelter property that ADEQ considered would be representative of background conditions. These wells are a subset of the 2006 ESI wells shown on Figure 3-4 (the remaining wells were sampled in May 2006, as discussed below).

The arsenic concentration in the main Humboldt Water System Municipal Well (GW-533639), two domestic wells located near the former Humboldt Smelter property (GW-805189 and GW-567387), and the background well (GW-507388) exceeded the arsenic MCL of 10 µg/L. The reported lead concentration exceeded the MCL in a sample from one of these wells (GW-567387). The arsenic concentrations in samples from the municipal wells ranged from 5.9 to 11.6 µg/L, which is slightly lower than the arsenic concentration in the background well (17.2 µg/L). The highest arsenic concentration (306 µg/L) was reported in a sample collected from well GW-567387, located south of the former Humboldt Smelter property (Figure 3-4).

In May 2006, ADEQ sampled six additional domestic wells (GW-512734, GW-551874, GW-586144, GW-599489, GW-634755, and GW-900344) to investigate the presence of metals and cyanide in drinking water wells near the Site (Figure 3-4). The arsenic concentrations exceeded MCLs in samples from all six wells. Copper, lead, mercury, and selenium were detected at concentrations below the MCLs.

Arsenic, boron, cobalt, copper, cyanide, lead, manganese, mercury, molybdenum, nickel, selenium, sodium, and/or vanadium concentrations were significantly higher in samples collected from seven of the domestic wells than in the wells considered representative of background conditions. The results exceeded the HRS criteria for an observed release to groundwater; however, the Site contribution to the elevated metals concentrations observed in groundwater at these locations is not clear from the spatial distribution of the results.

Based on the results from the PA/SIs and the groundwater samples collected specifically for the ESI, the ESI identified the following hazardous substance sources associated with the Site.

- MTP at the former Iron King Mine property
- Small Tailings Pile (now the former Small Tailings Pile, removed in 2011) just north of the former Iron King Mine property
- Waste rock at the former Iron King Mine property
- Tailings, ash (dross), and slag at the former Humboldt Smelter property
- Sediments in Chaparral Gulch and Galena Gulch

The ESI concluded that arsenic and zinc had been released to surface water in lower Chaparral Gulch, but that analytical data did not indicate arsenic and zinc had been released to the Agua Fria River.

3.3.5 2008 Ironite Products Company/North American Industries Sampling (Brown and Caldwell, 2009b)

As a result of the PA/SI performed by ADEQ in 2002 (ADEQ, 2002), Ironite Products Company received notification from EPA requesting additional site characterization for the Ironite Products Company property and adjacent properties. Under the ADEQ VRP, Ironite Products Company retained Brown and Caldwell to perform surface and subsurface soil sampling. Sampling was performed in March and June 2008, after the Ironite Products Company property had transferred ownership to NAI. The results are documented in the *Sampling Report, Former Ironite Products Company Facility* (Brown and Caldwell, 2009b) prepared for NAI.

Sampling was performed within and in the vicinity of the NAI property (the former Ironite Products Company property) (Figure 3-1B). The primary objectives of the sampling were to:

- Evaluate the impacts of stormwater runoff and dust from the NAI property (including the NAI Operations area and the majority of the MTP) to adjacent properties.
- Determine whether the tailings on the NAI property had impacted groundwater quality and whether controls may be required to reduce or prevent such impacts in the future.

The field investigation included collection and analysis of the following samples (Brown and Caldwell, 2009b):

- 153 soil (and tailings) samples (locations are shown on Figure 3-1B), including the following:
  - 57 near-surface samples (depth of 6 to 18 inches) from 26 locations at the NAI Operations area and MTP (sample locations beginning with “S” on Figure 3-1B)
  - 23 subsurface samples (maximum depths of 15 to 105 feet) from 6 borings on the MTP (borings B-1 through B-6 on Figure 3-1B)
  - 73 near-surface samples from 36 locations on 12 commercial, industrial, or residential parcels adjacent to the NAI property (sample locations beginning with “OS” on Figure 3-1B)
- 2 surface water samples (SW-1 and SW-2) from two onsite retention ponds (see Figure 3-2)

All soil (and tailings) samples were analyzed for arsenic, lead, and mercury. Subsets of the samples were also analyzed for additional metals, pH, organic carbon content, soil texture, dry bulk density, acid-base accounting (ABA) parameters, and synthetic precipitation leaching procedure (SPLP) metals. Surface water samples were analyzed for total recoverable arsenic and lead.

Near-surface and subsurface sampling in the portion of the MTP on NAI property contained very high concentrations of arsenic (maximum concentration of 13,000 mg/kg), lead (maximum concentration of 24,000 mg/kg), and mercury (maximum concentration of 160 mg/kg).

Samples of tailings collected from portions of the MTP on adjacent properties (State of Arizona property south of the NAI property and Kuhles property north and northwest of the NAI property) contained similarly high concentrations of arsenic, lead, and mercury. Much lower concentrations of arsenic (maximum of 110 mg/kg), lead (maximum of 79 mg/kg), and mercury (maximum of 0.7 mg/kg) were detected in soil samples from the other adjacent properties.

The surface water sample collected from one of the MTP retention ponds (see Figure 3-3; the specific pond number was not reported) contained very high concentrations of total arsenic (198 mg/L) and total lead (1.54 mg/L). Significantly lower concentrations were detected from retention pond 100-003F in the NAI Operations area (total arsenic of 0.065 mg/L and total lead of 0.049 mg/L).

3.4 Removal Actions

Two soil removal actions have been conducted at residential and municipal properties in response to the detection of concentrations of arsenic and lead in surface soil exceeding the site-specific action levels set by EPA.

The first removal action was performed in 2006 and 2007 by Brown and Caldwell on behalf of Ironite Products Company, as required by the Settlement Agreement. A larger-scale TCRA was completed in 2011 by EPA in conjunction with E & E.

The source documents describing each of these efforts are provided in Appendix D, including:

- *Removal Action Completion Report* (Brown and Caldwell, 2007 [2007 Removal Report])
- *Iron King Mine – Humboldt Smelter Removal Report, Dewey-Humboldt, Yavapai County, Arizona* (E & E, 2012 [2012 Removal Report]).

The specific properties where removal actions have been conducted are indicated on Figure 3-5. The details of the soil removals performed at each property are summarized in Table 3-3. Figure 3-5 differentiates the removal action areas as a "complete" removal action, in which surface soil from more than 50 percent of the undeveloped portion of the property was removed, and a "partial" removal action, which was subject to a hot spot removal only.

3.4.1 2006-2007 Removal Action, Ironite Products Company/Brown and Caldwell (Brown and Caldwell, 2007)

In the 2006 Settlement Agreement, EPA determined that Ironite Products Company, as an owner and operator of the fertilizer facility, was a responsible party and was liable for performance of a response action and for response costs incurred. EPA documented that a release of hazardous substances had occurred from the Ironite Products Company facility, and the removal action was necessary to protect public health, welfare, or the environment. The basis for the Settlement Agreement was a determination that arsenic concentrations in soil at four properties were greater than the screening level of 100 mg/kg. This determination relied on the EPA Removal Assessment of 17 properties conducted by Ecology and Environment, Inc. (E & E) (2005) (Section 3.3.3). Results from ADEQ (2002) sampling under the PA/SI of the former Iron King Mine property (Section 3.3.1) and EPA inspections at the site (Section 3.2.1) were also incorporated in the Settlement Agreement as supporting documentation.

In 2006, under the ADEQ VRP, Ironite Products Company contracted Brown and Caldwell to perform arsenic delineation sampling and analysis, determine excavation boundaries pursuant to an arsenic action level of 23 mg/kg, and conduct the removal of contaminated soil at four residential properties identified as Property #2 (referred to in this RI Report as O02), Property #3 (referred to in this RI Report as O03), Property #4 (referred to in this RI Report as 171/O04), and Property #7 (referred to in this RI Report as O07), in accordance with the Settlement Agreement. The removal action is documented in the 2007 Removal Report (Brown and Caldwell, 2007); a copy of the report is included in Appendix D.

Figure 3-5 shows the location of properties O02, O03, 171/O04, and O07. Table 3-3 summarizes the details of the soil removals performed at each property. This removal action predates the sampling performed on the former Ironite Products Company property (now NAI property) and adjacent properties by NAI (see Section 3.3.5).

3.4.1.1 Properties O02, O03, and 171/O04

According to the 2007 Removal Report, delineation sampling was completed at properties O02, O03, and 171/O04 in June and July 2006. This sampling involved the collection of 168 soil samples at depths of 0.5, 1, 2, and 3 feet bgs. The arsenic concentrations in 66 samples exceeded the action level defined in the Settlement Agreement of 23 mg/kg arsenic, with the majority of exceedances concentrated at the 0.5-foot bgs depth (Brown and Caldwell, 2007). The 2006 delineation sampling data were not incorporated into the Site database or the analyses in this RI because (1) coordinates were unavailable and (2) the properties were subject to the removal action.

The horizontal and vertical extents of necessary removal actions were refined using the 2006 delineation sampling data. A total of 1,604 yd^3 of soil was excavated from the affected properties and consolidated in the MTP (1,030 yd^3 from O02, 140 yd^3 from O03, and 434 yd^3 from 171/O04, as indicated in Table 3-3 and the 2007 Removal Report). This amounted to a removal of more than 50 percent of the surface soil in the undeveloped portion of each property, and thus these properties were classified as being subject to a “complete” removal action.

Activities performed by Ironite Products Company did not include collection of confirmation or verification samples after removal of soil. However, EPA collected verification samples on a grid layout at properties O02, O03, and 171/O04 after the excavation activities were completed. Coordinates and analytical data were not available for confirmation samples (Brown and Caldwell, 2007), so these data were not included in the RI dataset.

3.4.1.2 Property O07

The original proposed excavation boundary for Property #7 encompassed the current extent of properties O06 and O07 (see Figure 9 of Brown and Caldwell, 2007). Property O07 includes a house and a barn (current Yard ID of O07C) and a dirt road (O07B) that splits the property, and the rest is bare dirt. Property O06 includes a house. Excavation was proposed as a result of a high arsenic concentration (570 mg/kg) detected at one location (07-G) southeast of the house on Property O07 (O07C) during the EPA 2005 Removal Assessment (E & E, 2005). Arsenic detections at remaining sample locations on Property O07 ranged from 21 to 56 mg/kg during the 2005 investigation, and concentrations on Property O06 ranged from 13 to 75 mg/kg. In 2006, the property owner denied further access to the property, and delineation sampling was unable to be performed. Access was granted in May 2007 to conduct limited soil removal surrounding the arsenic hot spot. Soil was excavated in a 15- by 15-foot area to a depth of 1 foot bgs (yielding a volume of 8 yd^3), and consolidated within the MTP (Brown and Caldwell, 2007). Confirmation samples were not collected following excavation.

Property O07 was subsequently subdivided into four yards (O07A, O07B, O07C, and O07D) and additional sampling was performed in 2014 as part of the ERT Data Gap RI (Lockheed Martin SERAS, 2015) (see Section 4.5.13). New yard O07C is where the 15- by 15-foot excavation was performed in 2007; this yard is classified on Figure 3-5 as a partial removal action because less than 50 percent of the undeveloped portion was subject to the removal action. Elevated arsenic (352 mg/kg) and lead (1,170 mg/kg) concentrations were detected in one sample collected in 2014 from yard O07B, along the unpaved road that transects O07. Concentrations were below the RI screening levels of 194 mg/kg arsenic and 400 mg/kg lead (see Section 6.3) in all other samples collected in 2014 from yards O07A, O07B, O07C, and O07D, and in all samples collected in 2005 from O06 and O07 (excluding the hot spot sample 07-G, which was excavated as part of the removal action).

Properties O06 and O07, which were included in the original proposed excavation boundary, were classified as having undergone limited hot spot removal in this RI, because although soil excavation was performed, one 2014 sample remained with elevated arsenic (352 mg/kg) and lead (1,170 mg/kg) concentrations for yard O07B. Risk calculations were not performed for properties O06 and O07 because the combined properties had been substantially remediated except for this one “hot spot” sample, and 52 of 53 samples collected on these properties were below RI screening levels.

3.4.2 2011 Removal Assessment and Time-Critical Removal Action, EPA (E & E, 2011)

The EPA Region 9 Emergency Response Section conducted a removal assessment and a TCRA in 2011 on properties that contained significantly elevated concentrations of lead and arsenic in surface soil. Section 104 of CERCLA authorizes a TCRA in instances where there is a release (or threatened release) of a hazardous substance, pollutant, or contaminant that may present an imminent and substantial danger to public health or welfare or a threat to the environment. The TCRA is an interim action; other properties with Site contamination above cleanup levels will be addressed in the future, either through another removal action or during the final cleanup action identified in EPA's Record of Decision.

EPA tasked the E & E Superfund Technical Assessment and Response Team to provide technical assistance. The removal assessment involved a review of historical soil data and the completion of two additional sampling events at properties in the Town of Dewey-Humboldt. The 2011 removal assessment data were not incorporated into the Site database or the analyses in this RI because (1) coordinates were unavailable and (2) some of the properties were subject to a subsequent removal action.

The 2011 removal assessment resulted in the determination that 13 properties should be subject to a TCRA (*Iron King Mine – Humboldt Smelter Assessment Report, Dewey-Humboldt, Yavapai County, Arizona* [E & E, 2011]). These properties contained some of the highest residential arsenic and/or lead concentrations known at the time of the removal action, and/or were located in high-risk zones (for example, Sweet Pea Lane adjacent to the northwest corner of the former Humboldt Smelter, near the location of the historic rail spur). The affected properties are listed in Table 3-3, and included 11 residential properties, one municipal property, and the Small Tailings Pile (now former Small Tailings Pile, located on a 40-acre residential parcel north of the MTP). Figure 3-5 shows the locations of these properties.

EPA conducted the TCRA between September and November 2011, and excavated those areas of each property where soil was found to have arsenic and lead concentrations in excess of site-specific action levels (38 mg/kg and 23 mg/kg, respectively) (E & E, 2012). These action levels were set by EPA as the site-specific background concentration estimates derived in the Supplemental RI (EA, 2011). As discussed in Section 6, updated background concentrations have been calculated for this RI using a much larger dataset of soil samples collected between 2002 and 2013.

According to the 2012 Removal Report (E & E, 2012), a total of 6,339 yd^3 of soil was removed from the residential and municipal properties, consolidated with the MTP and hydroseeded. In addition, 21,500 yd^3 of soil was removed from the Small Tailings Pile and transferred to a temporary pad on the southeast side of the MTP and covered with a fixative agent. Additional details regarding the extent of soil removal at each property are provided in Table 3-3.

Following the completion of soil excavation activities, confirmation sampling was performed at the excavation surface of each property. At all residential and municipal properties, except 208 and 244, the results of confirmation sampling indicated that arsenic and lead concentrations exceeded the site-specific action levels; therefore, snow fence was placed in the bottom of the excavation to provide a visual barrier between the contaminated soil and clean backfill material (E & E, 2012). The excavations at the residential and municipal properties were backfilled with clean fill material imported from four separate borrow sources in Arizona, and graded.

At the former location of the Small Tailings Pile, 5 of the 12 confirmation samples collected from the excavation floor indicated concentrations of arsenic and lead that were below the site-specific action levels. The Small Tailings Pile had been removed to the depth of the original grade, and no additional removal was conducted at confirmation sample locations that were found to exceed the action level. Coordinates were not readily available for confirmation sample locations; therefore, these locations are not included in this RI Report dataset. Following soil removal at the Small Tailings Pile, EPA restored the grades and drainage patterns in the removal area to convey stormwater to Chaparral Gulch and protect against future erosion. Restoration included placement of coarse riprap and construction of a 400-foot diversion channel (E & E, 2012).

As part of the TCRA, EPA also applied a soil sealant to the surface of the dross at the former Humboldt Smelter property (E & E, 2012). Approximately 12 acres of dross piles on the Humboldt Smelter property were sprayed with a fixative called Gorilla-Snot. The application of the fixative was conducted to reduce dispersion of the ash by wind and rain.

SECTION 4

Remedial Investigations

The principal finding of the pre-NPL investigations and removal assessments described in Section 3 was that hazardous materials, primarily metals, had been released at the former Iron King Mine and former Humboldt Smelter properties, and contaminant sources included the following:

- The MTP at the former Iron King Mine property
- The Small Tailings Pile (now the former Small Tailings Pile, removed in 2011) north of the former Iron King Mine property
- Waste rock at the former Iron King Mine property
- Tailings, ash (dross), and slag at the former Humboldt Smelter property
- Sediments in Chaparral Gulch and Galena Gulch

Given the focused objectives and limited scope of the initial investigations, ADEQ and EPA determined that the sources, the nature, and the extent of contamination required further characterization. After inclusion of the Site on the NPL in 2008, EPA performed various investigations to provide the full characterization of contamination associated with the Site, which together have been used to form the basis for this RI Report.

This section summarizes the objectives, scope, and methods of the four phases of investigations performed after inclusion of the Site on the NPL. Physical site characteristics identified through these investigations and other Site references form the basis of the discussion in Section 5 (Physical Site Characteristics). Section 6 (Data Evaluation Methodology) provides a description of data usability; the selection of screening levels, background levels, and COIs; an overview of the development of the APSI; and identification of exposure areas within the APSI. The nature and extent of contamination based on these findings is provided in Section 7 (Nature and Extent of Contamination).

4.1 Overview of the Remedial Investigation Phases

EPA performed four phases of investigations between 2008 and 2015.

Phase	Investigation Name	Performed by
Phase 1	2008 to 2009 Initial RI	Performed by EPA’s contractor EA Engineering, Science, and Technology, Inc. (EA, 2010)
Phase 2	2010 and 2012 Supplemental RI	Performed by EPA’s contractor EA Engineering, Science, and Technology, Inc. (EA, 2011)
Phase 3	2012 to 2013 Background and Surface Soil Sampling	Performed by EPA Region 9 (EPA, 2012b, 2012c)
Phase 4	2013 to 2015 Data Gap RI	Performed by EPA’s Environmental Response Team and their contractor Lockheed Martin Scientific, Engineering, Response and Analytical Services (Lockheed Martin SERAS, 2015; also referred to as the “ERT report” in this section)

The broad objectives of the four phases of the RI were to identify source areas and historical releases; evaluate the nature and extent of contamination; estimate background concentrations; develop a CSM; evaluate the fate and transport of contamination; assess human health and ecological risks; and perform other studies applicable to the development and evaluation of potential remedial alternatives in the FS.

The media sampled during these investigations included:

- Surface soil
- Subsurface soil
- Sediment
- Surface water
- Groundwater
- Ambient air

Samples were also collected of waste rock, tailings, slag, and dross. The medium assigned to these source materials was standardized as either “soil” or “sediment,” depending on the location and degree of saturation, for inclusion in the Site database and presentation on the figures.

Figures 4-1 through 4-6 show the locations of samples collected from each media during each phase of investigation. Due to the large number of surface soil samples, these locations are separated into four figures associated with the four different phases of investigation (Figure 4-1A, 4-1B, 4-1C, and 4-1D). Each figure shows all surface soil samples as gray circles, with samples associated with the subject phase shown in color. For the same reason, the subsurface soil samples were separated into three figures: an overview figure showing all locations (Figure 4-2A), a figure highlighting former Iron King Mine property locations (Figure 4-2B), and a figure highlighting former Humboldt Smelter property sample locations (Figure 4-2C).

The data collected by EPA during the various phases of the RI and background sampling were combined with data collected during the pre-NPL PA/SIs, the 2006 ESI, and the 2008 Ironite Products Company/NAI sampling. Data without sample coordinates, locations within a subsequent removal action extent, and data flagged as rejected due to quality issues were excluded from the RI dataset (see Section 6 for additional discussion). EPA used the remaining dataset to assess the nature, extent, fate, and transport of Site contamination, as well as baseline human health and ecological risks.

4.2 Phase 1: 2008 to 2009 Initial Remedial Investigation

Phase 1, the initial phase of the RI, was performed by EPA contractor EA during several mobilizations in 2008 and 2009.

Soil, sediment, surface water, groundwater, and ambient air were sampled and analyzed to:

- Determine the nature and extent of contamination.
- Conduct both human health and ecological risk assessments.
- Gather sufficient information so that the EPA could select a remedy that eliminates, reduces, or controls risks to human health.

In addition to investigation of source areas on the former Iron King Mine property and former Humboldt Smelter property, sampling was also performed on residential properties in the Town of Dewey-Humboldt and other offsite areas.

The sampling effort approach and methodology is defined in the *Sampling and Analysis Plan* submitted to EPA in September 2008 (EA, 2008). The findings of this initial phase of the RI are summarized in the *Remedial Investigation Report, Iron King Mine - Humboldt Smelter Superfund Site, Dewey-Humboldt, Yavapai County, Arizona,* prepared by EA, dated March 2010 (EA, 2010; also referred to herein as the Initial RI report). The following subsections provide an overview of the investigation, followed by a description of the objectives, methodology, and scope of the investigation (organized by media sampled).

4.2.1 Overview

The following key components and project objectives were identified for the initial phase of the RI (EA, 2008):

- Area reconnaissance to:
  - Establish background multimedia sample locations
  - Establish onsite and offsite soil sampling locations
  - Identify outfalls and surface water pathways and establish surface water/sediment sampling locations
  - Identify private and municipal drinking wells for tap water sampling
  - Establish monitoring well locations
  - Perform a radiological screening survey
- Data collection activities included the following:
  - Demonstration of Methods Applicability Study to evaluate the effectiveness of field analysis over a range of solid matrices
  - Meteorological data to support the ambient air sampling program
  - Ambient air samples for inorganic analysis to determine sources and evaluate potential offsite migration of airborne contamination
  - Surface and subsurface soil samples for nature and extent characterization
  - Groundwater samples from one deep (bedrock) and five shallow (alluvial) newly installed monitoring wells
  - Tap water samples from private and municipal wells
  - Sediment and surface water samples from the Agua Fria River, Chaparral and Galena Gulches, outfalls/washes, and in the area of the Chaparral Gulch Dam
  - Sediment and surface water samples from five retention ponds on the former Iron King Mine property and one retention pond on the former Humboldt Smelter property
  - Volumetric estimates of the mine and smelter wastes
  - Stormwater evaluation of Iron King Mine drainage pathways
  - Geotechnical testing data from soil borings
  - Historical Section 106 review
  - Ecological habitat survey
  - Ancillary investigatory activities necessary for the RI and subsequent FS

The sampling activities performed for each media (soil, sediment, surface water, groundwater, and ambient air), as well as other ancillary studies conducted, are described below.

4.2.2 Soil Sampling

EA collected soil samples from the former Iron King Mine and Humboldt Smelter properties; residential, commercial, or public properties within the Town of Dewey-Humboldt; and locations assumed to represent background conditions. EA collected approximately 860 surface soil samples and approximately 120 subsurface soil samples from these areas.

4.2.2.1 Former Iron King Mine and Humboldt Smelter Properties

EA employed a combination of random and judgmental sampling to determine sample locations on the former Iron King Mine and Humboldt Smelter properties to characterize source areas (EA, 2010). EA used the Visual Sampling Plan (Pacific Northwest National Laboratory, 2007) to establish the random sample locations. EA selected judgmental sample locations based on operational history, historical site evidence (such as photographic documentation, previous sampling results, input from Site stakeholders), and field observations.

Surface soil sample locations are shown on Figure 4-1A; subsurface soil sample locations are shown on Figure 4-2A. Figure 4-2B provides detailed subsurface sample locations on the former Iron King Mine property and vicinity, and Figure 4-2C provides detailed subsurface sample locations on the former Humboldt Smelter property and vicinity. For this RI, surface soil samples were defined as samples with a beginning depth of 2 feet bgs or shallower, and subsurface soil samples were defined as samples with a beginning depth of greater than 2 feet bgs.

EA collected surface samples at depth intervals of 0 to 0.5 foot bgs, and 0 to 2 feet bgs. Most of the subsurface samples were collected at depths of 2 to 4 feet bgs and 4 to 7 feet bgs. The shallowest of these samples were collected using a sample scoop; a direct-push rig was used to collect the deeper samples. EA composited the samples over the recovered soil depth range before submitting them for analysis.

All soil samples were analyzed for Target Analyte List (TAL) metals. A subset of samples was analyzed for hexavalent chromium, VOCs, SVOCs, pesticides/polychlorinated biphenyls (PCBs), pH, perchlorate, asbestos, dioxins/furans, and anions (nitrates, nitrite, and sulfate). Most of the samples analyzed for organic constituents (VOCs, SVOCs, and PCBs) were collected from the judgmental sample locations where organic chemicals were suspected to have been used or stored.

EA also collected samples of waste materials (for example, tailings, dross, and waste rock) and analyzed these samples for ABA parameters and SPLP. The ABA parameters include analysis of sulfur forms and neutralizing potential, which are used to estimate the acid-generating potential of these materials. The SPLP targets the immediately leachable metals in the sample. The leachate is analyzed for metals, and the results compared to groundwater and surface water screening criteria to evaluate the potential for metals to leach from these media. Section 8 of this RI (Contaminant Fate and Transport) includes further discussion of the analytical methods and interpretation for the ABA and SPLP analyses.

4.2.2.2 Residential, Commercial, and Public Properties

Soil samples were collected from 48 residential, commercial, and public properties in the Town of Dewey-Humboldt to investigate off-property migration of contaminants from the former Iron King Mine and former Humboldt Smelter properties (EA, 2010). Accessible properties located downwind (north-northwest) and in proximity to the source areas were selected for sampling. At each of the 48 residential properties, EA collected nine surface soil samples at a depth of 0 to 2 inches, and a single sample at a depth of 10 to 12 inches. Figure 4-1A illustrates the surface soil sample locations. The samples were analyzed for TAL metals analysis.

4.2.2.3 Background

EA collected soil samples from areas assumed representative of background for three background surface soil types identified in the Site vicinity (the most common of which is the Balon gravelly sandy clay loam [Section 5.4.4]). EA collected 10 surface soil samples (0 to 2 feet bgs) from each of the three soil types. These samples were analyzed for TAL metals; samples collected from the locations closest to the former Humboldt Smelter property were also analyzed for dioxins/furans. In 2012 and 2013, EPA conducted a greatly expanded soil sampling effort that supersedes the background analysis performed by EA. Section 4.4 describes the 2012 to 2013 EPA Background and Surface Soil Sampling activities. Section 6.2 discusses the approach used to establish background concentrations of metals in soil for this RI, which included soil data collected as part of Site investigations performed between 2002 and 2013.

4.2.3 Sediment Sampling

EA collected and analyzed approximately 200 sediment samples to assess site-related impacts and potential sediment/surface water migration pathways. Figure 4-3 shows the sample locations. Samples were classified as sediment by EA based on the location and degree of saturation at the time of sampling, whether transitory or permanent. Many of the sediment samples were collected from terrestrial habitats such as intermittent surface water features, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways.

Sediment samples were collected at intervals of up to 400 to 500 linear feet along Chaparral Gulch, Galena Gulch, and the Agua Fria River, with sample locations targeted to provide a good spatial distribution in pools, reaches, and inside of major bends where impacted sediments would accumulate. EA also collected samples from reaches of Chaparral Gulch, Galena Gulch, and the Agua Fria River that were upstream of the former Iron King Mine and Humboldt Smelter properties to provide a basis of comparison for samples collected from downstream reaches. Figure 4-3 shows the sample locations.

Additional sediment samples were collected from retention ponds, current and historical drainage pathways at the former Iron King Mine property and Humboldt Smelter properties, and associated outfalls/washes.

All sediment samples were analyzed for TAL metals. In addition, select samples were analyzed for pH, perchlorate, dioxins/furans, nitrate, and ABA and SPLP metals.

4.2.4 Surface Water Sampling

EA collected and analyzed approximately 80 surface water samples to assess surface water impacts from the Site (EA, 2010). The samples were collected at intervals of up to 400 to 500 linear feet along the Chaparral Gulch, Galena Gulch, and Agua Fria River, targeting pools, reaches, and inside of major bends. EA also collected surface water samples from upstream locations of the Agua Fria River to evaluate potential changes in contaminant concentrations upstream and downstream of the source areas. Surface water samples were also collected from retention ponds on the former Iron King Mine property. Figure 4-4 shows the sample locations.

The samples were collected using a dip spoon for total inorganic and metal analyses and a peristaltic pump for dissolved analyses (EA, 2010). The samples were analyzed for total and dissolved TAL metals, perchlorate, major anions, major cations, and total dissolved solids (TDS).

4.2.5 Groundwater Sampling

EA collected approximately 100 groundwater samples from 60 private and municipal supply wells and 6 newly installed monitoring wells to assess potential groundwater impacts from the Site and better understand the regional hydrogeology. The following monitoring wells were installed (see Figure 4-5 for well locations):

- Two shallow wells at the toe of the MTP (MW-04S and MW-05S) to assess water quality, the potential for acid mine drainage, and the extent of tailings dewatering
- One shallow well southeast of the tailings pile to assess water quality and the potential for acid mine drainage (MW-03S)

- One deep well (MW-06D) adjacent to the former Glory Hole to assess the nature and extent of impacts to the bedrock aquifer from mining activity and from the potential waste material landfilled in the Glory Hole
- Two shallow (alluvial) wells at the former Humboldt Smelter property to assess water quality and the potential for contaminant leaching to groundwater:
    - One shallow well along the bank between the former Humboldt Smelter property and the Agua Fria River (MW-01S)
    - One shallow well near the Smelter Tailings Swale (MW-02S)

Section 5 (Table 5-4) provides construction details for the EPA monitoring wells. Reliable construction details for the supply wells sampled by EA are not readily available (EA, 2010).

Groundwater samples were collected during the Fall of 2008, Spring of 2009, and Fall of 2009. The private and municipal supply wells were sampled from existing taps and after purging the well. The newly installed monitoring wells were sampled by low-flow methods using temporary sampling pumps (EA, 2010). The samples were analyzed for total and dissolved TAL metals, VOCs, SVOCs, explosives, perchlorate, major anions, major cations, and TDS.

4.2.6 Ambient Air Sampling

Ambient air samples were collected in 2008 and 2009 to characterize the current sources and potential offsite migration of airborne contamination from fine-grained materials (primarily tailings and dross) at the former Iron King Mine property and former Humboldt Smelter property. A meteorological station was installed at the former Iron King Mine property to monitor wind speed and direction at the Site during the period of sampling (between August 2008 and August 2009) (EA, 2010). Air samplers were placed at the former Iron King Mine property, former Humboldt Smelter property, and in the Town of Dewey-Humboldt. Two of the locations within the Town of Dewey-Humboldt were thought to be representative of background air concentrations (EA, 2010). Table 4-1 provides additional detail on the ambient air samples, including sample group (background vs. on-property, etc.), sampling equipment used, and sample date range. Figure 4-6 shows the air monitoring and meteorological station locations.

Samples were analyzed for total suspended particulates (TSP), particulate matter less than 10 micrometers in diameter (PM_{10}), and inorganics. TSP data measure the total amount of matter in the air (such as dust particles). PM_{10} data measure the concentration of particulates in the air that may enter the lungs.

In August 2008, EA collected approximately 90 ambient air samples (up to six stations per day for 5 days for 3 weeks) using BGI PQ100 samplers (PQ100). From December 2008 through September 2009, EA collected approximately 140 24-hour ambient air samples at four locations on a 6-day rotating basis, also using PQ100 samplers. Metals analysis was conducted on the TSP samples.

Samples were also collected at locations AIK-02, AES-01, and AHS-02A using continuous particulate monitors (Thermo Electron TEOM Series 1400a [TEOM]). These samplers included an Automatic Cartridge Collection Unit intelligent sampling system that was triggered by a particulate concentration to characterize particulate migration during high-wind events (EA, 2010). TEOM samples were collected when specified TSP thresholds were exceeded, and as a result, are used to evaluate episodic events rather than chronic conditions.

4.2.7 Other Ancillary Studies

Other studies were performed during the 2008 to 2009 initial phase of the RI to support RI and FS evaluations. These studies included the following:

- Biological evaluation performed by EnviroSystems Management, Inc. (EnviroSystems) (a subcontractor to EA)
- Cultural resource and historical building survey for the former Iron King Mine and former Humboldt Smelter properties performed by ACS for EPA
- Analysis of aerial photography for the mine, smelter, and adjacent areas performed by EPA
- Wetland and riparian evaluation of Chaparral Gulch performed by WestLand Resources, Inc. (a subcontractor to EA)
- Research projects performed by University of Arizona’s Superfund Basic Research Program in collaboration with EPA and ADEQ.
- Reuse assessment for the former Iron King Mine and Humboldt Smelter properties performed by E2 Inc. and funded by the EPA Abandoned Mine Lands Team

An overview of these studies is provided below.

4.2.7.1 Biological Evaluation

The objective of the biological evaluation was to identify representative species and potential receptors of concern as part of the ERA (EA, 2008). EnviroSystems performed the biological evaluation and documented both terrestrial and aquatic habitat types present within and surrounding the former Iron King Mine and Humboldt Smelter properties, and nearby surface water features. For terrestrial habitats and riparian corridors, a biologist recorded the dominant plant communities and species, and the presence of any wildlife species. For aquatic habitats, the general hydrology and morphology was recorded in addition to the identification of species present.

The findings are documented in the *Biological Evaluation of the Iron King Mine - Humboldt Smelter Superfund Site* (EnviroSystems, 2009). The general spatial distribution of habitats was provided on base maps, and the project area was evaluated for the potential presence of listed or special-status species and associated habitat features. Federal, state, and local regulations concerning the biological environment of the project area were identified and evaluated; and recommendations regarding compliance with these regulations were provided.

The findings are incorporated into the discussion of the ecological setting for the Site in Section 5 (Physical Site Characteristics) and Section 10 (Baseline ERA) of this RI Report.

4.2.7.2 Cultural Resources and Historic Building Survey

In 2007, Archaeological Consulting Services, Ltd (ACS) conducted a cultural resource inventory and historic building survey for EPA in compliance with Section 106 of the National Historic Preservation Act. This effort consisted of archival research, a Class III intensive cultural resource survey, and a historic building survey. The findings of this evaluation are documented in the report titled *A Cultural Resource and Historic Building Survey for a Remedial Investigation/Feasibility Study at the Iron King Mine-Humboldt Smelter Superfund Site, Dewey-Humboldt, Yavapai County, Arizona* (ACS, 2008).

A copy of the ACS report is included as Appendix B in this RI Report.

ACS performed archival research at several repositories in Arizona, including the Sharlot Hall Museum and the Yavapai County Recorder’s Office in Prescott; the Dewey-Humboldt Historical Society in Dewey-Humboldt; and the Arizona Department of Mining and Mineral Resources in Phoenix (EA, 2010; ACS, 2008). Primary and secondary sources (for example, newspaper articles, mining records, Sanborn fire insurance maps, historical photographs, title plats, etc.) documenting the history of the Iron King Mine and Humboldt Smelter were the main resources examined at these repositories. During the field assessment, ACS documented historical features and completed a building survey.

The ACS report documents the results of the analyses, provides an overall history of the area, and discusses the more prominent features. The ACS report identified archeological sites at the mine and smelter and provided recommendations for managing these areas during remedial activities. ACS assessed the Iron King Mine and Humboldt Smelter for eligibility as a historic district for listing on the National Register of Historic Places. Neither the Iron King Mine nor the Humboldt Smelter were recommended for listing on the National Register of Historic Places because many of the original structures have been demolished, a significant amount of ground disturbance has taken place, and other factors (ACS, 2008).

The ACS (2008) cultural resource report is a major source of information for the history of the Iron King Mine and Humboldt Smelter properties presented in Section 2 of this RI Report.

4.2.7.3 Aerial Photograph Analysis

In 2008, EPA conducted an aerial photograph analysis of the Site to document the nature, extent, and location of contaminants and other observable conditions of environmental significance. The findings of this analysis are documented in the report titled *Aerial Photographic Analysis of the Iron King Mine/Humboldt Smelter Site*, dated December 2008 (EPA, 2008d); a copy of the report is included as Appendix C in this RI Report.

EPA performed the analysis using 14 dates of historical black-and-white, color, and color infrared aerial photographs covering the period from 1940 through 2003. All 14 dates of photography were analyzed, and 8 dates were selected for inclusion in the EPA (2008d) report. The report contains two volumes. The first volume includes the text description and photographic analysis; the second volume contains the aerial photographs and interpretive overlays.

EA used the findings from this analysis to guide the design of soil and sediment collection during the initial phase of the RI (EA, 2010). The findings from the analysis were also used to support the description of operational details and location of historical features at the former Iron King Mine and Humboldt Smelter properties, as well as the timing of geomorphic changes to Chaparral Gulch (Section 2.3.3.2 and Section 8).

4.2.7.4 Wetland Delineation and Riparian Evaluation System Survey

In 2008, WestLand Resources, Inc., performed a wetland delineation and riparian evaluation survey of conditions of the lower portion of Chaparral Gulch from the Tailings Floodplain on the former Humboldt Smelter property to Chaparral Gulch's confluence with the Agua Fria River. The findings are documented in the report titled *Riparian Evaluation and Jurisdictional Determination, Lower Chaparral Gulch, Humboldt Smelter Site, Humboldt, Arizona* (WestLand Resources, Inc., 2009).

Jurisdictional wetlands are considered "special aquatic sites" under the Clean Water Act and specific methods are used in their identification and delineation. A formal jurisdictional wetlands determination was not performed. However, the presence and quality of wetland conditions were documented to support the eventual development and evaluation of remedial alternatives. The wetlands evaluation was based on the triple-parameter approach of documenting vegetation, soil, and hydrologic conditions, as defined by the U.S. Army Corps of Engineers (Environmental Laboratory, 1987), along with supplementary information on delineation of wetlands in the arid western states (Environmental Laboratory, 2006).

As part of the riparian evaluation, riparian areas in Chaparral Gulch were identified and categorized based on landscape stability, contamination severity, and plant community attributes. The findings of the wetland delineation and riparian evaluation are incorporated into the discussion of the ecological setting for the Site in Section 5.

4.2.7.5 University of Arizona Superfund Basic Research Program

EPA and ADEQ worked in collaboration with the University of Arizona's Superfund Basic Research Program staff on a variety of research projects. These projects included (EA, 2010):

- Physical and chemical characterization of dust resulting from the Site, including an evaluation of particulate emissions, number distribution, mass distribution, and chemical speciation by size fraction of particulates.
- Implementation of a phytostabilization field trial. Phytostabilization is a process that uses native plants and soil amendments to revegetate impacted soils (such as tailings) and reduce the mobility of heavy metals and dust.
- Analysis of the physical chemistry, metal, and mineral content of mine tailings.
- Implementation of a community garden project to determine the metal and nutrient content of vegetables grown in local gardens.

These data were not incorporated into the RI dataset because the original reference documents and data were not available.

4.2.7.6 Reuse Assessment

In 2009 and 2010, EPA's Abandoned Mine Lands Team worked with the community, site owners, and other stakeholders to perform a reuse assessment for the former Iron King Mine and Humboldt Smelter properties. The purpose was to clarify reuse goals and identify reuse considerations to inform cleanup activities and local planning efforts. The assessment also examined opportunities for siting renewable energy projects at the Site, in particular, the feasibility of using renewable energy technologies to meet potential onsite light industrial/commercial electricity demand or to generate grid-tied electricity, which would allow use of renewable energy and electricity from the grid.

The findings of this assessment are presented in the document titled *Planning for the Future: Reuse Assessment for Iron King Mine – Humboldt Smelter Superfund Site, Town of Dewey-Humboldt, Yavapai County, Arizona* (E2 Inc., 2010). Data gathered during the reuse assessment informed the land use/reuse information presented in Section 5 (Physical Site Characteristics) of this RI Report.

4.3 Phase 2: 2010 and 2012 Supplemental Remedial Investigation

Phase 2 of the RI was performed by EA in 2010 on behalf of EPA. Evaluation of the Phase 1 RI results led to the identification of additional data needs. To address these data needs, the supplemental investigation (Phase 2 of the RI) included:

- Collection and analysis of soil samples from additional residential, commercial, and public properties to investigate off-property migration of contaminants via aerial dispersion and other transport pathways
- Collection and analysis of soil samples from additional background locations to better assess naturally occurring levels of metals in soil
- Collection and analysis of samples from source areas to assess whether the media exceeded the criteria for a characteristic hazardous waste

- Collection and analysis of additional groundwater samples from EPA monitoring wells, private supply wells, and municipal wells
- Collection of geotechnical data to evaluate the stability of the MTP
- Evaluation of preliminary cover options for the MTP

The initial findings of the supplemental phase of the RI are summarized in the report titled *Remedial Investigation Report Addendum, Iron King Mine – Humboldt Smelter Superfund Site, Dewey-Humboldt, Yavapai County, Arizona*, prepared by EA, Inc., dated February 2011 (EA, 2011). Following publication of this report, EA installed additional monitoring wells and performed an additional groundwater sampling event in 2012; these data are included in the Site database although they have not been published previously. The scope of the 2010 and 2012 investigations are discussed below.

4.3.1 Soil Sampling

EA collected 1,360 surface soil samples (less than 2 feet bgs) from 120 residential, commercial, and public properties in the Town of Dewey-Humboldt in May and June 2010. Samples were collected to investigate off-property migration of contaminants from the former Iron King Mine property and the former Humboldt Smelter property via aerial dispersion and other transport pathways. Parcels were selected based on the predominant wind direction, which is from the south-southeast, and proximity to the source areas (EA, 2011). The 2010 sample data were combined with data from the 2005 Removal Assessment (Section 3.3.3) and the 2008 to 2009 Initial RI, resulting in a total of 185 parcels sampled to date.

Figure 4-1B shows the sample locations. At each of the 120 properties, EA collected 9 surface soil samples from 0 to 2 inches bgs and a single sample at a depth of 10 to 12 inches bgs. The samples were analyzed for TAL metals.

EA also collected soil samples from areas assumed representative of background in the Site vicinity. Locations were selected based on the dominant geologic formations and soil types in the area. Other considerations included proximity to the Site and distance from other anthropogenic disturbances. Thirty background surface soil samples were collected from 0 to 2 feet bgs.

4.3.2 Groundwater Sampling

EA collected a total of 45 groundwater samples in May 2010 from 30 private and municipal supply wells (18 of which had been previously sampled during the 2008 to 2009 initial investigation) and 6 EPA monitoring wells to provide additional data regarding potential groundwater impacts. The samples were analyzed for total and dissolved TAL metals, major anions, major cations, and TDS (EA, 2011).

Based on the supplemental investigation results, EA installed six new monitoring wells (MW-7S, MW-7D, MW-8S, MW-8D, MW-9S, and MW-9D) (see Figure 4-5) in 2012 and performed an additional comprehensive sampling event for all the EPA monitoring wells installed to date (MW-01 through MW-09) and two supply wells. This work was completed after the Supplemental RI report was published. The monitoring wells were installed to provide more information on the contaminant concentrations at and downgradient from the MTP. The samples were analyzed for total and dissolved TAL metals, major anions, major cations, and TDS.

4.3.3 Engineering Evaluation of the MTP and Preliminary Cover Options

GEI Consultants, Inc. (GEI) performed an engineering evaluation of the MTP to evaluate the long-term stability of the MTP and develop preliminary cover alternatives.

GEI prepared the report titled *Cover Alternatives Evaluation for Iron King Mine Main Tailings Pile*, dated October 20, 2010 (GEI, 2010), which presents considerations, concepts, and estimated costs for installing a cover on the MTP. The document also identified data gaps that would be key to the development of MTP cover alternatives, including engineering material properties of the tailings and underlying native foundation material.

To address the data gaps identified in the GEI (2010) report, a Phase 1 Subsurface Exploration of the MTP was performed in 2012. This investigation included cone penetrometer testing (CPT) at 41 locations in the MTP. The depths of the CPT ranged from about 10 to 64 feet bgs on the lower MTP and 20 to 112 feet bgs on the upper MTP. GEI provided oversight and evaluated the results of the testing, and documented the findings in the report titled *Phase 1 Subsurface Exploration of Iron King Mine Main Tailings Pile* (GEI, 2012). This report discusses the estimated thickness of tailings at CPT locations, the presence of weaker lenses and zones of tailings, the stratigraphy and variability of tailings, and shear wave velocities of tailings.

In addition to the GEI work performed, EA collected Shelby tube samples in 2012 from boreholes advanced in the MTP during installation of monitoring wells MW-08S and MW-09S. These samples were submitted for physical and geotechnical testing, including particle size analysis, specific gravity, Atterberg limits, hydraulic properties testing, shear strength testing, and consolidation properties testing.

The geotechnical data and evaluations discussed above will be used to support further analysis of the stability of the MTP as part of the FS.

4.4 Phase 3: 2012 to 2013 Background and Surface Soil Sampling

Phase 3 of the RI included surface soil sampling performed by EPA in 2012 and 2013; sample locations are shown on Figure 4-1C. Based on the Phase 1 and 2 RI data (collected between 2008 and 2010), EPA concluded that the distribution of metals, and in particular arsenic, in soils within and surrounding the former Iron King Mine property and the former Humboldt Smelter property is influenced by a number of factors, including the following (EPA, 2012b):

- Mine and smelter operations
- Historical smelter stack emissions and aerial dispersion of tailings, dross, or fine-grained particulates
- Geologic conditions, which are highly variable and result in varying metals concentrations in area soil
- Anthropogenic factors, such as using mine waste or material from other quarries as construction fill, road base, or landscaping material
- Use of arsenic-containing fertilizers or pesticides

Prior to 2012, a significant number of samples had been collected in residential areas close to the former Iron King Mine property and the former Humboldt Smelter property, primarily to the north of and between the two properties. However, insufficient data had been collected at locations further from the property boundaries, and the lateral and vertical coverage was insufficient to calculate background concentrations, account for variations in geology and natural soil chemistry, and account for the multiple sources of metals identified above.

EPA staff performed soil sampling in 2012 and 2013 over an area of approximately 20 square miles to better represent variations in geology and natural soil chemistry at locations that were not expected to be impacted by the Site, and to better characterize contamination in non-residential areas impacted by the Site. Specific objectives described for the April 2012 sampling included the following (EPA, 2012b):

1. Obtain a spatially well-spread sampling distribution of surface soils at distances up to 2 miles from Site source materials.
2. Obtain a spatially well spread and surface-correlated distribution of deeper soils (on the order of 1 foot) for comparison to surface soil data.
3. Collect sufficient data to analyze spatial trends in metals concentrations and correlate these with geology and distance from the Site source materials.
4. Collect sufficient data to obtain statistical calculations of parameters such as background threshold values for subpopulations that may be smaller than the entire dataset, and may have many points removed due to various influences.
5. Gain additional information about the sources, including if possible, source profiling information for comparison to background areas.

Soil samples were collected in January, April, May, and June 2012 from approximately 360 locations (see Figure 4-1C) at depths ranging from 0 to 1.3 feet. Soil samples were collected in April, May, and June 2013 from approximately 270 locations at depths ranging primarily from 0 to 2 feet. Samples were analyzed by a combination of x-ray fluorescence (XRF) and laboratory analytical methods.

Field reports describing the April 2012 sampling were prepared by Jeff Dhont, EPA Region 9 Remedial Project Manager (EPA, 2012b) and Greg Nagle, EPA Region 9 Laboratory Environmental Scientist (EPA, 2012c). Field documentation of the other sampling events is currently unavailable; however, objectives and methods were similar for the sampling events.

In the April 2012 event, EPA staff collected samples at the surface (in the top ½ inch of soil), and at most locations, at depths of approximately 1 foot. EPA collected global positioning system (GPS) readings, identified geologic formations, took photographs, and noted the terrain and depositional environment at each sample location (EPA, 2012b). EPA analyzed samples in the field using a portable XRF analyzer. Each sample was analyzed in duplicate by turning the bag to expose a different surface and performing an identical XRF analysis. Samples were analyzed by the XRF for a range of elements including arsenic, lead, copper, zinc, iron, manganese, mercury, nickel, and selenium; however, the XRF was calibrated for arsenic and lead, as these were the primary elements of interest. Data quality of the XRF results also was assessed using standard reference materials (EPA, 2012c). Approximately 25 percent of the samples from the April 2012 event were submitted for confirmation laboratory analysis.

The data collected in 2012 and 2013 were used in the development of the *Soil Background Study Report* (CH2M, 2015; included as Appendix E in this RI Report), in combination with soil data collected as part of other site investigations between 2002 and 2013, as discussed further in Section 6. The data were used to calculate defensible background concentrations for arsenic, lead, and other metals, and establish an approximate geographic extent of potential site-related impacts. This area is referred to as the *area of potential site impact (APSI)* and is discussed in more detail in Section 6 of this RI Report. The APSI was determined by a rigorous and statistically based analysis of metals concentrations in soils spatially distributed up to 3 miles distant from the former mine and smelter operations. The APSI was based on several independent lines of evidence; its derivation is summarized in Section 6.2.5 and described in detail in Appendix E. The APSI was used to define the extent of Phase 4 of the RI (the data gap phase).

4.5 Phase 4: 2013 to 2015 Data Gap Remedial Investigation

Phase 4 of the RI consisted of additional investigations performed by EPA's ERT to satisfy data gaps. This section describes the data gap analysis performed on the information available from previous investigations (Section 4.5.1) documented in the *Data Gap Analysis Report* prepared in 2013 (CH2M, 2013); an overview of the additional investigations performed (Section 4.5.2); and a description of the objectives, methodology, and scope of each additional investigation (Sections 4.5.3 through 4.5.17). A summary of the investigation activities is also provided in Table 4-2.

4.5.1 Data Gap Analysis (2013)

Following the initial and supplemental phases of the RI, EPA evaluated available data and identified data gaps. The objective of this analysis was to identify data required to finalize EPA's understanding of the nature and extent of contamination associated with the Site, complete human health and ecological risk assessments, and develop and evaluate alternatives in an FS.

This section provides a brief overview of the approach used to identify data gaps and a brief summary of the data needs identified. Details on the data gap identification process and findings are presented in the *Data Gap Analysis Report* (CH2M, 2013). A description of the objectives, methodology, and scope of the fieldwork performed to satisfy the data needs is presented in the following sections.

The organization of this section is similar to the *Data Gap Analysis Report* and identifies the following:

- Data gaps for source areas
- Data gaps for potentially impacted areas
- Data gaps for groundwater and surface water
- Data gaps for risk assessments

4.5.1.1 Data Gaps for Source Areas

The source areas evaluated in the data gap analysis included:

- The former Iron King Mine property (including the MTP and former Mineworks area)
- The former Humboldt Smelter property (including tailings, slag, and dross areas)
- Lower Chaparral Gulch and Chaparral Gulch Dam

The data gaps for the source areas were primarily related to the adequacy of data available to define the nature and extent of contamination and the adequacy of data available to perform the FS. The following steps were performed in the data gap report (CH2M, 2013) for source areas potentially requiring remediation:

- Development of preliminary remedial action objectives (RAOs)
- Development of potential remedial alternatives
- Review of existing data
- Identification of data gaps for developing and evaluating potential alternatives for the FS

Data needs identified for the former Iron King Mine property, including the MTP and former Glory Hole, included the following:

- Areas were identified where the lateral extent of contamination was not sufficiently defined and step out samples were recommended.
- Additional geotechnical data needs were identified for evaluating the stability of the MTP, characterizing waste rock, and identifying sources of construction materials.
- Additional ABA data needs were identified to evaluate the potential for future generation of acidic water from the MTP.

The data gap analysis identified the following data needs for the former Humboldt Smelter property, including accumulations of tailings, slag, and dross:

- Additional investigation was needed to define the horizontal and vertical extent of the dross and smelter tailings.
- Survey measurements were needed to assess the stability of the slag pile.
- ABA and leachability data were needed for smelter tailings, dross, and slag.
- More detailed site topographic data were needed. This was a sitewide data gap that applied to both the Iron King Mine and Humboldt Smelter, as well as the surrounding impacted areas.

The data needs identified for the lower Chaparral Gulch and Chaparral Gulch Dam included:

- Additional sampling was needed to adequately characterize the extent of contamination in Chaparral Gulch above and below the dam, both at the surface and at depth.
- Geotechnical data were needed for sediment and tailings samples just upstream of the dam.
- Survey measurements of the dimensions of the dam were needed for stability analysis.
- ABA and leachability data for material at depth in Chaparral Gulch were needed to evaluate future potential for acid generation.

4.5.1.2 Data Gaps for Potentially Impacted Areas

The analysis identified data gaps for the following potentially impacted areas:

- Undeveloped areas close to the Site that could be developed in the future and may be accessed currently for recreational use
- In-town parcels of land within the central Humboldt area (Humboldt Proper) that are used for residential or commercial purposes
- Surface water drainage areas that may have been impacted by the source areas, including Galena Gulch and the reach of Chaparral Gulch upstream of the Tailings Floodplain

The data gaps for the potentially impacted areas primarily related to adequacy of the data to define the nature and extent of contamination. However, the data gap assessment also evaluated the adequacy of existing data for conducting the FS.

The data gap analysis for undeveloped areas identified a need for additional soil sampling in the following areas to delineate potential impacts by aerial deposition of windblown tailings and other source materials:

- Undisturbed areas north, south, and west of the MTP
- Undisturbed areas in the northern portion of central Humboldt

The following data need was identified for the parcels within Humboldt Proper:

- Extent of contamination for parcels within the northern portion of central Humboldt. It was recommended that a screening level evaluation be done by sampling a subset of the parcels in this area and detailed sampling be deferred to remedial design.

The following data needs were identified for the surface water drainage areas that may have been impacted by the mine- or smelter-related materials:

- Additional sampling of alluvium and tailings materials at surface and at depth in Chaparral Gulch to estimate the extent and volume of impacted materials
- Assessment of waste rock piles adjacent to Galena Gulch

4.5.1.3 Data Gaps for Groundwater and Surface Water

The data gap analysis for groundwater and surface water included developing preliminary RAOs and potential alternatives, reviewing existing data, and identifying data gaps for both determining the nature and extent of contamination and the potential fate and transport of the contaminants. For groundwater, existing data were reviewed to determine whether data were sufficient to characterize flow directions, hydraulic gradient, lithologic units, and contaminant distribution. Surface water data in Chaparral Gulch and the Agua Fria River were evaluated to determine if discharge measurements and water quality samples had been collected over a sufficient range in flows to adequately characterize the waterbodies.

For the hydrogeology and groundwater, the data gap evaluation identified the following data need:

- New monitoring wells to assess groundwater flow directions and gradients, lithologic and hydrostratigraphic conditions, and groundwater quality impacts from the site-related sources

For surface water, the data gap evaluation identified the following data need:

- Additional flow and water quality in Chaparral Gulch; existing data were limited

The data gap assessment also recommended that the following additional data be gathered from available published resources:

- Seasonal precipitation records
- Site topography for determining runoff catchment areas
- Rainfall/runoff relationships based on site material properties and site topography
- Annual hydrograph of the Agua Fria River at/near Dewey-Humboldt (from existing USGS station)
- 100-year design storm estimate

4.5.1.4 Data Gaps for Risk Assessments

To identify the data gaps for the HHRA, the results of the HHRA provided in Section 6 of the Initial RI report (EA, 2010) were reviewed with respect to methodology, exposure assumptions, toxicity assumptions, and risk characterization approaches. Default assumptions made in the HHRA that had a critical impact on the risk characterization results and introduced a substantial amount of uncertainty were targeted to determine whether site-specific data could be collected to meaningfully reduce the uncertainty. The primary data needs identified for the HHRA included:

- Additional data to assess site-specific bioaccessibility of arsenic and lead in site soils and residential properties
- Chromium speciation data to provide more realistic estimates of inhalation risk

To identify the data gaps for the ERA, existing documents and analytical data were reviewed to evaluate whether data were sufficient spatially and chemically to evaluate potential risks to ecological receptors. The available documents and data were reviewed to determine if data were sufficient to:

- Determine habitats and representative species.
- Evaluate potential risks to terrestrial ecological receptors for exposures within each area of interest and under Sitewide conditions (for large home range receptors).
- Evaluate potential risks to aquatic ecological receptors in the Agua Fria River.
- Address site-specific conditions including bioavailability and bioaccumulation in forage/prey items.

- Reduce uncertainties and provide better information for making risk management decisions. A screening-level ecological risk assessment (SLERA) was prepared as part of the 2008 to 2009 Initial RI (EA, 2010) and identified the following uncertainties and needs for additional data or analysis:
  - Assumptions made in the SLERA were highly precautionary and may overestimate risk.
  - Thresholds of effects should be developed for use in risk management.
  - Further evaluation of habitat quality should be completed for use in evaluating remedial alternatives.
  - Additional consideration is warranted in the Agua Fria River to determine if benchmark exceedances are truly indicative of ecological effects.

The primary tasks identified to address the ERA data gaps included:

- A reconnaissance-level biological survey should be performed of upland habitats and riparian corridors, and benthic environments in in the Agua Fria River.
- Biological and collocated soil samples should be collected to develop site-specific bioaccumulation factors.
- Additional water sampling locations were identified within the Agua Fria River for dioxins/furans and total organic carbon (TOC) analyses.
- Additional soil/sediment sampling was recommended along Chaparral Gulch from the former Iron King Mine property to the confluence with the Agua Fria River.

4.5.2 Overview of Data Gap Investigations Performed (2013 to 2015)

In July 2013, EPA's Superfund Division requested assistance from EPA's ERT to perform the additional investigations required to satisfy the identified data gaps (Phase 4 of the RI). Lockheed Martin personnel from the SERAS contract assisted ERT in completing this work. Lockheed Martin SERAS drafted a Supplemental Field Investigation Work Plan (Lockheed Martin SERAS, 2013a) and Quality Assurance Project Plan (QAPP) (Lockheed Martin SERAS, 2013b) to outline the objectives, approach, and methods that would be used to address the data needs identified in the data gap report (CH2M, 2013).

Fieldwork was conducted between 2013 and 2015. ERT and Lockheed Martin SERAS performed soil sampling on 10 residential properties in August 2013. These parcels were presumed to contain elevated concentrations of lead and arsenic in surface soils. Remaining fieldwork was performed by ERT/Lockheed Martin SERAS between late January and late October 2014, with the exception of survey work on the slag pile (crack monitoring) that was completed in 2015.

The fieldwork conducted by ERT and Lockheed Martin SERAS included:

- Collection of approximately 6,000 surface soil samples, 600 subsurface soil samples, 43 groundwater samples, 44 sediment samples, and 39 surface water samples
- Subsurface investigation of Humboldt Smelter and Chaparral Gulch, including installation of approximately 100 borings, collection of approximately 500 samples, installation of 5 piezometers, and development of a conceptual geologic model for the Chaparral Gulch study area
- A surface geophysical investigation of the Smelter Tailings Swale and the Tailings Floodplain
- Collecting surface and subsurface samples of the Smelter Plateau soil, imported dross, and slag piles
- Completing three deep borings through the MTP and sampling shallow borings around the margin of the MTP
- Assessing waste rock in the former Mineworks area and Galena Gulch

- Installation of nine monitoring wells and review of available regional geological and hydrogeological information
- Development of a geologic model for the Site, with a focus on Chaparral Gulch, using both 3-dimensional (3D) and 2-dimensional (2D) visualization software
- Groundwater sampling of new and existing monitoring wells during two monitoring events
- Monitoring of surface water and sediment in Chaparral Gulch and the Agua Fria River, including surface water sampling during baseline and storm conditions, sediment sampling to determine sediment thickness and metals concentrations, and hydraulic analysis of lower Chaparral Gulch
- Performance of a biological survey focused on the habitat in and surrounding the riparian corridor of the Agua Fria River
- Bioassessment sampling to provide estimates of bioaccumulation in support of the human health and ecological risk assessments
- Soil ecological testing, including a plant growth study and agronomic analysis, to determine the feasibility of revegetating Site source areas
- Collection of approximately 4,700 soil samples for arsenic and lead analysis from approximately 380 residential properties
- Collection of approximately 340 surface soil samples in areas surrounding the former Iron King Mine property
- Analysis, validation, and data management
- Surveying to provide location and elevation data for the new monitoring wells, monitoring of the slag pile for potential movement along existing cracks, and gathering and mapping topographic data
- Construction material survey to identify local, offsite sources of natural materials that could be used in future Site remediation
- Humboldt Smelter stack structural condition assessment

Figures 4-1D through 4-5 show the locations for surface soil, subsurface soil, sediment, surface water, and groundwater samples, respectively, collected during these investigations. Table 4-2 provides a summary of sampling and other activities performed by ERT and Lockheed Martin SERAS. A description of the investigation objectives, methodology, and scope follow.

Details are presented in the *Final Report, Iron King Mine Site, Dewey-Humboldt, Arizona* (Lockheed Martin SERAS, 2015 [also referred to herein as the “ERT report”). A copy of the ERT report is included as Appendix F in this RI Report.

The structure of the following subsections generally matches the sections in the ERT report for ease of reference. Parenthetical italicized references to specific sections within the ERT report are also provided to assist the reader in finding information in Appendix F.

4.5.3 Subsurface Investigation: Former Humboldt Smelter Property and Chaparral Gulch

A subsurface investigation within Chaparral Gulch, the Smelter Tailings Swale, and the Tailings Floodplain was performed to meet the following objectives (Lockheed Martin SERAS, 2013a, 2015):

- Determine the horizontal extent, depth, and volume of tailings and impacted alluvial material within Chaparral Gulch, the Smelter Tailings Swale, and Tailings Floodplain.

- Use XRF technology to estimate the origin and depositional history of tailings based on whether the tailings are lead-rich (Iron King Mine) or copper-rich (Humboldt Smelter).
- Determine the acid-generating potential of the tailings.
- Assess layering and moisture content of alluvium and develop a schematic fluvial stratigraphic profile.
- Measure perched groundwater levels and conceptualize the hydraulic gradient in the Chaparral Gulch floodplain.
- Generate chemical and geotechnical data that will be used in the FS to develop and evaluate remedial alternatives, such as (a) evaluating erosion potential of tailings, (b) designing a potential conveyance channel, (c) designing a remedy that moves or consolidates tailings, and (d) designing a remedy involving in-place closure of the tailings.
- Determine the slope angle of the upstream surface of the concrete tailings dam, loading on the dam, and physical measurements of the dam to assess its structural stability for use in development and evaluation of remedial alternatives in the FS.

The methodology and scope of the subsurface investigation included the following:

- Between Third Street and the Chaparral Gulch Dam, a track-mounted sonic drilling rig was used to advance 99 shallow borings in Chaparral Gulch to define the horizontal and vertical extent of tailings. An additional 16 borings were drilled at select locations within the Smelter Tailings Swale to define the vertical extent of the tailings. Borehole depths ranged from approximately 1.5 to 38 feet with most ending at the top of bedrock (competent, weathered, or unlithified). Locations are shown on Figure 4-2C.
- Over 500 samples of unconsolidated material were collected and analyzed with a field portable XRF analyzer for lead, arsenic, and other metals of interest.
- A number of samples were also collected for laboratory analysis or testing, which included TAL metals, SPLP followed by metals analysis, ABA, and physical properties characterization (grain size, plasticity, and moisture content).
- Five piezometers were installed at four borehole locations within the Chaparral Gulch floodplain and adjoining Smelter Tailings Swale to monitor groundwater fluctuations during the course of the field investigation. The well construction information is discussed below in Section 4.5.7.
- A conceptual geologic model of the Chaparral Gulch study area was prepared, which is based on available geologic reports for the region and local area.

(Additional details are provided in Section 1 of the ERT report, included as Appendix F of this RI Report.)

4.5.4 Surface Geophysical Investigation: Smelter Tailings Swale and Tailings Floodplain

A surface geophysical investigation of the Smelter Tailings Swale and Tailings Floodplain was conducted to determine the subsurface geometry (variable thickness) and volume of the tailings (Lockheed Martin SERAS, 2015).

The methodology and scope of the surface geophysical investigation included the following:

- An initial site visit and examination of the variable local topography
- Acquisition and modeling of Schlumberger array (multi-electrode resistivity) data to assist in mapping the thickness of transported and redeposited mine tailings

- Analysis of terrain conductivity response measurements
- Delineation and mapping of tailings deposits based on the collected data
- Volume estimation of tailings

The initial site visit was conducted on November 16, 2013, to determine the appropriate geophysical methods to employ. Transported and redeposited tailings observed during the site visit did not appear to be significantly different in grain size from underlying in-place alluvial sediments. Tailings were distinguishable from underlying sediments mainly by color. Also, there was significant local topographic variation, and the thickness of tailings increases across the Tailings Floodplain from a minimal thickness in upstream areas to greater than 20 feet in the area of the dam. These observations indicated that geophysical methods relying on density (gravity, seismic) or acoustic velocity variation (seismic) were not appropriate. Significant variation in local topography was thought to preclude the effectiveness of the geophysics using magnetic susceptibility differences (magnetics, magnetic gradiometer). A ground-penetrating radar system was tested, but was ineffective due to limited depth of penetration.

The best approach at distinguishing and mapping the thickness of the tailings was determined to be multi-electrode resistivity, which would exploit the electrical conductivity (resistivity) contrast between the tailings and underlying alluvium. Frequency-domain electromagnetics (terrain conductivity) was also used as a secondary method. These geophysical methods were used in conjunction with soil borings and surveyed tailings contacts to estimate the volume of tailings in the study area.

(Additional details are provided in Section 2 of the ERT report, included as Appendix F of this RI Report.)

4.5.5 Dross, Plateau Soils, and Slag Investigations: Former Humboldt Smelter Property

ERT/Lockheed Martin SERAS performed investigations of the dross area, Smelter Plateau soils, and slag piles on the former Humboldt Smelter property. The objectives, methodology, and scope are summarized in the following subsections.

(Additional details are provided in Section 3 of the ERT report, included as Appendix F of this RI Report.)

4.5.5.1 Dross Characterization

After closure and dismantling of the Humboldt Smelter, a large quantity of dross was imported in the late 1950s and early 1960s for reprocessing to recover aluminum and zinc (see Section 2.1 for more details). The objectives of the dross investigation were as follows (Lockheed Martin SERAS, 2013a, 2015):

- Delineate the spatial extent, volume, and primary contaminants in the dross.
- Determine the acid-generating potential of the dross.
- Delineate the spatial extent and volume of contaminated soils beyond the dross, and determine if contamination in non-dross materials can be attributable to the dross.

The methodology and scope of the dross investigation included the following:

- Approximately 300 unconsolidated samples were collected from 140 hand auger and seven sonic-drilled borehole locations to determine the spatial extent and volume of the dross material. Investigation depths were variable, usually averaging around 2 to 3 feet below grade. In one area (a sonic-drilled borehole), the maximum drilling depth was approximately 11 feet below grade. Collected samples were also used to determine the spatial extent and volume of contaminated soils (or natural deposits) beyond and beneath the dross. Sample locations are shown on Figure 4-1D and Figure 4-2C (locations beginning with “ASH”).

- All samples were analyzed for lead, arsenic, and other metals of interest using a field portable XRF analyzer. A limited number of samples were also collected for laboratory analysis or testing, which included TAL metals, SPLP metals, ABA, dioxins/furans (two samples), and physical properties characterization (grain size, plasticity, and moisture content).

4.5.5.2 Plateau Soil Characterization

The Smelter Plateau is located south of the former Pyrometallurgical Operations area. The objectives of the plateau soil investigation were as follows (Lockheed Martin SERAS, 2013a, 2015):

- Characterize the nature and extent of arsenic and lead contamination in the soil covering the Smelter Plateau.
- Characterize the basic geotechnical properties of the soil covering the Smelter Plateau. Data will be used in the FS for the conceptual design of a possible containment cell to store the dross material.

Surveys performed on the primary slag pile to assess pile stability are discussed in Section 4.5.16.
The methodology and scope of the plateau soil investigation included the following:

- Boreholes were advanced up to approximately 7.5 feet in depth at five locations using a track-mounted sonic drilling rig. Continuous samples (from grade to final depth) were collected at each location and logged for lithology and moisture conditions. Sample locations are shown on Figure 4-2C (locations beginning with "PS").
- A total of 11 samples were collected and analyzed for lead, arsenic, and other metals of interest using a field portable XRF analyzer. A limited number of samples were also collected for TAL metals analysis and physical properties characterization (grain size, plasticity, and moisture content).

4.5.5.3 Slag Pile Characterization

Two slag piles exist on the Humboldt Smelter property. The primary slag pile is located directly north-northeast of the smelter stack and a smaller satellite slag pile is located approximately 1,400 feet southeast of the smelter stack (see Figure -2-2). The objectives of the slag investigation were as follows (Lockheed Martin SERAS, 2013a, 2015):

- Assess the stability of the primary slag pile given that cracks are present.
- Determine the acid-generating potential of the slag.
- Confirm whether differences exist in the chemical characteristics of the primary and satellite slag piles.

The methodology and scope of the slag investigation included the following:

- Three surface samples of slag material were collected: one from the primary slag pile and two from the satellite slag pile.
- All samples were analyzed for TAL metals, SPLP metals, ABA, and specific gravity.

4.5.6 Main Tailings Pile and Waste Rock Investigations: Former Iron King Mine

ERT/Lockheed Martin SERAS performed an investigation of the MTP and waste rock to meet the following objectives (Lockheed Martin SERAS, 2013a, 2015):

- Shallow boreholes: Determine the extent of mine-related contamination along the margin of the MTP.

- MTP investigation: Complete three deep borings through the MTP into the underlying Hickey Formation to assess the following:
  - Bedrock integrity: Assess bedrock characteristics beneath the MTP (rock quality, fracturing, etc.).
  - Geotechnical properties of tailings: Assess moisture conditions with depth, stability of the MTP, and liquefaction potential.
  - Acid mine drainage potential: Assess buffering capacity of tailings and acid mine drainage potential.
  - Perched groundwater level monitoring: Assess the hydraulic connectivity between the MTP and underlying Hickey Formation by constructing three monitoring wells that terminate near the base of the tailings (above the Hickey Formation).
- Waste Rock Investigation: Assess waste rock piles near the former Iron King Mine operations area and within Galena Gulch for possible use as cover material.

The methodology and scope of each activity are summarized in the following subsections.

(Additional details are provided in Section 4 of the ERT report, included as Appendix F of this RI Report.)

4.5.6.1 Shallow Boreholes

Shallow boreholes were advanced along the margin of the MTP and sampled as follows (Lockheed Martin SERAS, 2015):

- A track-mounted sonic drilling rig was used to advance 11 boreholes (up to 24 feet in depth). Five boreholes were drilled in an area west of the MTP (borings IKM-SB01 through IKM-SB05; see Figure 4-2B). Six boreholes were drilled in an area southwest of main retention ponds (below the 1964 Blow Out; see Figure 2-1) (borings IKM-SB06 through IKM-SB11; see Figure 4-2B).
- Continuous samples were logged for lithology, moisture conditions, presence of perched water, and occurrence and depth of the tailings.
- Approximately 50 samples were collected from the 11 boreholes. The samples were analyzed for arsenic, lead, and other metals of interest using a field portable XRF analyzer.
- Two samples were analyzed for TAL metals.

4.5.6.2 MTP Investigation

The methodology and scope of the MTP investigation was as follows (Lockheed Martin SERAS, 2015):

- A truck-mounted sonic drilling rig was used to advance three deep boreholes through the MTP and into underlying native material (the Hickey Formation). One boring was drilled on the lower MTP (MTP-SB01); two were drilled on the upper MTP (MTP-SB02 and MTP-SB03) (see Figure 4-2B). Continuous sonic core samples were collected from grade to final depth in each borehole to assess the physical characteristics of both the tailings and underlying Hickey Formation (weathered or unlithified bedrock). Total borehole depths ranged from approximately 77 to 134 feet below grade, which extended 28 to 30 feet beyond the base of the tailings, into the underlying Hickey Formation.
- Three to four unconsolidated samples were collected from each borehole for analysis of TAL metals, SPLP metals, and ABA. Samples were collected near the current ground surface, in wet intermediate zones within the tailings, near the base of the tailings (two boreholes), and in the underlying Hickey Formation.

- Standard penetration tests (SPTs) were conducted at regular intervals in each borehole and a total of 48 samples (retrieved with either Shelby tubes or thick-wall ring-lined samplers) were obtained for a number of laboratory geotechnical tests.
- Upon drilling termination at each location, the boreholes were backfilled to the base of the tailings and completed as monitoring wells MTP-MW1, MTP-MW2, and MTP-MW3 (see Figure 4-5). The bottom of the well screens were positioned near the base of the tailings (additional well construction information is provided in Section 4.5.7. Pressure transducers (with data logging capability) were installed in all three wells to monitor perched or transient groundwater within the MTP over a 1-year period; however, the wells were dry for the entire period of monitoring.

4.5.6.3 Waste Rock Investigation

The waste rock investigation was focused on waste rock stockpiled west of the former Mineworks area and along Galena Gulch, southwest of the former Iron King Mine property (see Figure 1-2). The methodology and scope of the investigation was as follows (Lockheed Martin SERAS, 2015):

- A visual survey of waste rock piles was performed to assess their suitability as construction material for possible use during future site restoration. The waste pile boundaries were surveyed using a GPS.
- Three samples of waste rock material were collected west of the former Mineworks area and analyzed for TAL metals, SPLP metals, and ABA.

4.5.7 New Monitoring Well Installation: Sitewide

Prior to 2014, information pertaining to groundwater quality within the Site study area was based on data from private water supply wells and 12 existing EPA monitoring wells. Borehole lithologic logs and water level information is generally very limited and/or not available for the private wells. Additional Sitewide monitoring wells were installed in 2014 to supplement the existing monitoring well network and meet the following objectives (Lockheed Martin SERAS, 2013a, 2015):

- Better define groundwater flow directions and gradients in the unconfined and semiconfined aquifers.
- Develop a better understanding of the vertical movement of groundwater and dissolved contaminants and further define the lateral and vertical extents of the dissolved contamination.
- Further define the hydrogeology and hydrostratigraphy.
- Assist in developing a robust CSM of groundwater flow and contaminant fate and transport.

A total of 14 monitoring wells and piezometers were installed in the following areas (see Figure 4-5). Well construction information and a discussion of the hydrogeology and hydrostratigraphy is presented in Section 5 (Physical Site Characteristics) of this RI Report.

(Well logs and construction diagrams are presented in Appendix 5A of the ERT report, included as Appendix F of this RI Report.)

- **Main Tailings Pile (MTP).** Monitoring wells MTP-MW1 through MTP-MW3: These wells were dry during the entire monitoring period. The monitoring wells are also discussed in Section 4.5.6.
- **Tailings Floodplain, Quaternary Alluvium/Tailings.** Piezometers CHF-MW-01 through CHF-MW-03, STS-MW-04S, and STS-MW-04I: Piezometer STS-MW-04S was dry during the entire monitoring period. These piezometers are also discussed in Section 4.5.3.
- **East of Highway 69, Tertiary Hickey Formation.** Monitoring Wells MW-10S, MW-11S, and MW-12S/D.
- **Iron King Volcanics (IKV).** Monitoring Wells MW-02D and MW-10D.

The methodology and scope of the new well installation task included the following:

- Sonic drilling was primarily used for borehole advancement. However, for the three deep wells (MW-02D, MW-10D, and MW-12D), downhole air hammer drilling was required at some point during borehole advancement to reach targeted depths. For all sonic drilling, the boreholes were continuously cored, sampled, and logged from ground surface to final depths. During borehole advancement with the hammer bit, washed drill cuttings were periodically collected for lithologic description.
- Monitoring wells were constructed with 4-inch-diameter Schedule 80 polyvinyl chloride (PVC) riser pipe and varying lengths of 10 slot (0.010 inches) Schedule 80 PVC screen. Final depths for shallow wells (MW-10S, MW-11S, and MW-12S) ranged from 45 feet (MW-12S) to 77 feet (MW-11S) with all wells having screen intervals of 15 feet. Final depths for the deep wells ranged from 175 feet (MW-12D) to 356 feet (MW-02D) with screen intervals ranging from 30 to 50 feet. Final depths for the dry wells at the MTP ranged from 45 feet (MTP-MW1) to 106 feet (MTP-MW3). Subsequent to installation, the completed monitoring wells were developed using a combination of air lifting, surging, and pumping.
- Piezometers (CHF-MW-01 through CHF-MW-03, STS-MW-04S, and STS-MW-04I) were constructed with 2-inch-diameter Schedule 40 PVC riser pipe and 10-foot lengths of PVC screen. Final depths for the piezometers ranged from 8 to 28 feet.
- Lockheed Martin SERAS also reviewed the regional geology and hydrogeology, developed two geologic cross sections for the Site, reviewed groundwater fluctuations in the Chaparral Gulch floodplain piezometers, and assessed vertical groundwater gradients using selected well couplets (paired shallow and deep wells).

(Additional details are provided in Section 5 of the ERT report, included as Appendix F of this RI Report.)

4.5.8 Conceptual Geologic Model Development: Chaparral Gulch, Tailings Floodplain, and Smelter Tailings Swale

A preliminary CSM and 3D visualization model of the Chaparral Gulch Arroyo was developed to meet the following objectives (Lockheed Martin SERAS, 2015):

- Delineate the vertical and horizontal extent, volume, and the primary contaminant(s) of the Smelter Tailings Swale.
- Determine the volume of tailings in the Tailings Floodplain with concentrations greater than 400 mg/kg lead or greater than 200 mg/kg arsenic.
- Delineate the vertical and horizontal extent, and total volume of contaminated soil exceeding the specified lead and arsenic concentrations (400 mg/kg and 200 mg/kg, respectively).
- Constrain the hydrostratigraphy by:
    - Separating the major hydrostratigraphic units within Chaparral Gulch
    - Delineating important water-bearing zones
    - Assessing the groundwater flow pattern upgradient of the Chaparral Gulch Dam

Lithologic, XRF, and water level measurement data collected during the 2014 field investigation were used along with data acquired during previous investigations to develop a geologic model with focus on Chaparral Gulch. Both 3D and 2D visualization software was used. Components of the model included the following:

- A hydrostratigraphic schematic section, extending along the axis of Chaparral Gulch, from the former Iron King Mine property to the Chaparral Gulch Dam
- A number of stratigraphic profiles across Chaparral Gulch, between Third Street and the Chaparral Gulch Dam
- An isopach map of tailings within Chaparral Gulch showing their thickness and horizontal extent
- Depth to groundwater contours and schematic flow directions within the Chaparral Gulch area
- Visual illustrations showing the distribution of elevated lead-arsenic concentrations in unconsolidated deposits along Chaparral Gulch (at 5-foot depth intervals)
- Tabulated concentrations of arsenic, lead, and copper from over 500 borehole samples

(Additional details are provided in Section 6 of the ERT report, included as Appendix F of this RI Report.)

4.5.9 Groundwater Sampling: Sitewide

Groundwater samples were collected to meet the following objectives (Lockheed Martin SERAS, 2013a, 2015):

- Further evaluate contaminant distributions in groundwater throughout the study area.
- Develop a better understanding of groundwater chemistry.

The methodology and scope of the groundwater sampling included the following:

- Groundwater samples were collected on two occasions (July and October 2014) from both existing and new EPA monitoring wells (see Figure 4-5).
- The following sets of monitoring wells (or piezometers) were sampled: 10 existing monitoring wells, the six new 4-inch PVC wells, and four of the five new 2-inch PVC piezometers (within the Chaparral Gulch floodplain area). A number of wells, including the three new wells on the MTP, were found to be dry during both sampling events.
- Laboratory analysis of samples included the following: total TAL metals (unfiltered samples), dissolved TAL metals (filtered samples) and water quality parameters (alkalinity-carbonate-bicarbonate, chloride, fluoride, nitrate + nitrite, sulfate, phosphorus, total silica, dissolved organic carbon, and TDS). A number of field indicator parameters (for example, pH) were also recorded during both sampling events.
- Water levels were additionally recorded in the existing monitoring wells on three separate occasions (June, July, and October 2014) and in the new wells on two occasions (July and October 2014).
- ERT installed pressure transducers to collect continuous water level measurements from four alluvium monitoring wells in Chaparral Gulch (CHF-MW-01, CHF-MW-02, CHF-MW-03, and STS-MW-04I).

(Additional details are provided in Section 7 of the ERT report, included as Appendix F of this RI Report.)

4.5.10 Surface Water and Sediment Monitoring: Chaparral Gulch and Agua Fria River

Surface water and sediment sampling and monitoring were conducted to meet the following the objectives (Lockheed Martin SERAS, 2015):

- Assess the impact of Site sources on surface water quality in Chaparral Gulch and the adjoining Agua Fria River during the summer 2014 monsoon season when rainfall, surface water flow, and sediment transport are typically at their highest.

- Collect sediment samples in Chaparral Gulch from the base of the Chaparral Gulch Dam to the confluence with the Agua Fria River (over a distance of approximately 1,500 feet) to determine sediment thickness above underlying bedrock and metal concentrations within the sediments.
- Estimate peak discharges for surface water flow in Chaparral Gulch (downstream of the dam) during the summer 2014 monsoon season.

Two types of surface water samples were collected during this investigation:

- Baseline flow samples were manually collected during baseflow conditions. Baseflow is the surface water flow that occurs during non-stormwater flow conditions resulting from the accumulation of water in the watershed from past storm events.
- Stormwater samples were collected using dedicated sampling devices in the absence of field personnel. While the storms within this region can reach high intensity (typically occurring during July and August), they are generally both infrequent and of low duration. Thus, these runoff events are difficult to capture by field personnel.

The methodology and scope of the surface water and sediment sampling and monitoring included the following:

- Local rainfall was monitored by retrieving daily data from the National Weather Service's Website (forecast office in Flagstaff, Arizona). The closest weather station is located at Prescott Municipal Airport (Ernest A. Love Field), approximately 14.7 miles northwest of the Site.
- Six baseline samples (DAM-SW01 through DAM-SW06) were collected in May 2014 in Chaparral Gulch downstream of the dam and the Agua Fria River near the confluence (see Figure 4-4). Field measurements were obtained and samples were analyzed for total and dissolved TAL metals, general chemistry, major anions and cations, dissolved organic carbon, and TDS.
- Dedicated sampling devices were subsequently installed to monitor storm flows at nine locations within Chaparral Gulch and the Agua Fria River with an "SWD" designation (for example, SWD-03) (see Figure 4-4). Staff were deployed to the Site in July, August, and October 2014, subsequent to storm events with precipitation totals of approximately 0.5 inch or greater, to check the SWD sampling devices and retrieve water samples that had been collected. For all sampling events, it was found that some of the devices did not completely fill with water, thus limiting both the number of samples collected and types of analyses that could be performed (especially field measurements). Total TAL metals were analyzed for all locations when sample volumes were sufficient. For some locations, additional analyses included dissolved TAL metals, water quality parameters, and field indicator parameters.
- Sediment sampling was conducted in May 2014. Beginning at the base of the Chaparral Gulch Dam and at regularly spaced intervals downstream, a hand auger was advanced through the sediment at eight locations identified as DAM-SED01 through DAM-SED08 (see Figure 4-3) down to underlying bedrock (or what was perceived to be bedrock). At most locations, a minimum of two sediment samples (surface and total depth) were collected for pH paste testing (in the field) and analysis of TAL metals.
- Channel survey measurements were acquired at two locations in lower Chaparral Gulch (downstream of the dam) where pressure transducers had been installed by Lockheed Martin SERAS to monitor changes in flow height (or water surface elevation) from early July through late October 2014. Knowing the flow height, channel geometry, and other channel conditions, standard methods for open channel flow were used to determine peak discharges and associated channel velocities during the monitoring period.

(Additional details are provided in Section 8 of the ERT report, included as Appendix F of this RI Report.)

4.5.11 Biological Survey and Bioassessment Sampling: Sitewide and Agua Fria River

ERT/Lockheed Martin SERAS performed a biological survey within the Agua Fria River and bioassessment sampling at various locations across the Site. The objectives, methodology, and scope are summarized in the following subsections.

(Additional details are provided in Section 9 of the ERT report, included as Appendix F of this RI Report.)

4.5.11.1 Biological Survey

The objective of the biological survey was to assess riparian corridors and upland areas within the Site boundaries that would provide suitable habitat for wildlife. Because much of the habitat in and around the Site has previously been defined, the majority of the survey effort focused on the habitat in and surrounding the riparian corridor of the Agua Fria River.

The methodology and scope of the survey included the following:

- Benthic community and fish observations were documented at selected locations along the Agua Fria River and wildlife observations were recorded while traveling from one area to another throughout the Site. Benthic macroinvertebrate samples were also collected at seven locations along the Agua Fria River for archiving and, if required at some point in the future, more rigorous identification.
- Based on the survey work, aerial photograph analysis, and previous Site documents, a general habitat map was developed for the Site along with a tabulated summary of observed species and associated habitats.

4.5.11.2 Bioassessment Sampling

The objective of the bioassessment sampling was to provide estimates of bioaccessibility for the risk assessments. The methodology and scope of the sampling included the following:

- A total of 41 sediment samples and 18 surface water samples were collected along Chaparral Gulch and the Agua Fria River in May 2014 (see Figures 4-3 and 4-4). Samples were analyzed for TAL metals; select samples were also analyzed for a suite of water quality parameters, including:
  - Sediment and sediment/surface water pairs were collected at the 11 sampling locations within the Agua Fria River (sample IDs beginning with “AG-BIO”).
  - As part of the sampling effort outlined in Section 4.5.10, surface water and sediment samples with sample IDs beginning with “DAM” were collected primarily in lower Chaparral Gulch.
  - Sediment samples with IDs beginning with CH-BIO and CHD-BIO were collected along Chaparral Gulch from the former Iron King Mine property to the confluence with the Agua Fria River. No corresponding surface water was present in Chaparral Gulch upstream of the dam at the time of sampling in May 2014.
- Ten collocated plant material (primarily grass species) and surface soil (tailings) samples were collected from the MTP for analysis of TAL metals.
- Ten surface samples of tailings material were collected from the MTP for analysis of hexavalent chromium and in vitro bioaccessibility (IVBA) testing for lead and arsenic. Five additional soil samples were collected along Galena Gulch for IVBA analyses. These data will support the HHRA.

4.5.12 Soil Ecological Testing: Tailings Floodplain, MTP, and Dross

During the Data Gap RI field investigations, large, barren, unvegetated areas were observed on the Tailings Floodplain, northwest of the Chaparral Gulch Dam. These unvegetated areas are located in close proximity to well vegetated areas. The "soil" (primarily tailings) appeared superficially the same for the vegetated and unvegetated areas. The soil ecological testing was conducted to assess why some areas within the Tailings Floodplain are able to naturally revegetate while other large similar areas remain barren (Lockheed Martin SERAS, 2015).

The methodology and scope of the soil ecological testing included the following:

- A bench-scale plant growth study and agronomic analysis were conducted on a limited number of surface and near-surface samples collected from the Tailings Floodplain, the MTP, and dross area.
- Samples were characterized and tested in a controlled laboratory setting for their ability to support plant growth. Agronomic analyses included plant nutrients, pH, electrical conductivity, organic matter content, acid sulfate scoring, acid producing capability, bioaccessibility, percentage of sand/silt/clay, and soil textural class.

(Additional details are provided in Section 10 of the ERT report, included as Appendix F of this RI Report.)

4.5.13 Surface Soil Sampling: Residential Properties

Prior to the 2013 to 2015 data gap phase of the RI, soil samples had been collected from approximately 200 parcels in Humboldt Proper for the purposes of assessing the extent of contamination and evaluating the associated risk to residents (CH2M, 2013). The data indicated that the distribution of arsenic and lead concentrations are highly variable among parcels, likely due to anthropogenic causes such as grading during property development and importation of landscape materials. Sampling results also indicated significant variability in concentrations of metals such as zinc and copper, which were identified as indicator parameters for differentiating between the site-related and naturally occurring conditions. Refer to the *Soil Background Study Report* (CH2M, 2015; included in Appendix E) and the *Cultural Resource and Historic Building Survey* (ACS, 2008; included in Appendix B). Because of this variability in distribution of the primary contaminants of concern such as arsenic and lead, as well as the indicator metals, the extrapolation of existing data to parcels that have not been sampled is difficult.

Therefore, additional surficial soil sampling was conducted on residential properties located in the vicinity of the former Iron King Mine and Humboldt Smelter properties in 2013 and 2014. The field efforts focused on properties that may have been (or were believed to be) impacted by site-related contamination. The acquired data were used in this RI in conjunction with previously collected data to assess human health risk to residents.

In August 2013, ERT and Lockheed Martin SERAS performed soil sampling on 10 residential properties in the vicinity of the intersection of Jones and Well Streets (see Sample IDs "30W-#" and "36W-#" on Figure 4-2C for location). These parcels were presumed to contain elevated concentrations of lead and arsenic in surface soils. A total of 254 surface and 27 subsurface samples (9 samples at 10 to 14 inches; 9 samples at 22 to 24 inches; and 9 samples at 34 to 38 inches bgs) were collected and analyzed using a field portable XRF analyzer. The results are presented in the *Technical Memorandum: Accelerated Residential Sampling, Iron King Mine and Humboldt Smelter Superfund Site, Dewey-Humboldt, Arizona* (Lockheed Martin SERAS, 2013c). A copy of this technical memorandum is included in Appendix D of this RI.

The methodology and scope of the ERT and Lockheed Martin SERAS 2014 residential surface soil sampling included the following (Lockheed Martin SERAS, 2015); additional details on the methodology of the residential soil sampling program are provided in Section 6.6 of this RI, and Section 7 presents detailed figures that show sample locations by parcel:

- Lockheed Martin SERAS obtained property access with the assistance of ERT and defined residential property boundaries (using a geographic information system [GIS] database obtained from Yavapai County).
- In total, 4,400 samples were collected from 373 properties within the APSI in January through May 2014.
- Clean stainless steel spoons, stainless steel trowels, and hand augers were used to collect samples. Most sampling intervals were 0 to 2 inches, and 10 to 14 inches below grade.
- All soil samples were analyzed for lead, arsenic, and other metals of interest using a field portable XRF analyzer. Ten percent of the samples were submitted for laboratory confirmation analysis of TAL metals.
- A total of 40 soil samples were collected on residential properties for IVBA analysis for lead and arsenic to support the HHRA (21 samples were collected in 2014 by ERT and 19 samples were collected in April and May 2013 by EPA Region 9).

(Additional details are provided in Section 11 of the ERT report, included as Appendix F of this RI Report.)

4.5.14 Surface Soil Sampling: Non-Residential Areas

The objective of the non-residential surficial sampling effort was to evaluate metal concentrations, particularly arsenic and lead, in areas surrounding the former Iron King Mine property that had not been previously sampled. The 2008 to 2010 investigations had focused on areas immediately around the mine and smelter, but movement and distribution of contaminants into the surrounding landscape had not been thoroughly evaluated (Lockheed Martin SERAS, 2015).

The methodology and scope of the survey included the following:

- A total of 341 surface and near-surface samples were collected from non-residential areas surrounding the former Iron King Mine property, including peripheral areas, areas in the vicinity of Galena Gulch, and undeveloped areas.
- At all sampling locations, a soil sample was collected at the surface (0 to 2 inches bgs). A second deeper soil sample was also collected at most locations from a hand-augered boring, which usually extended to a maximum depth of 1 foot bgs. A third deeper sample was collected from a few locations at depths up to 3 feet bgs. The soil conditions at most sampling locations were hard and very rocky, making it challenging to collect samples at depth.
- All samples were analyzed for lead, arsenic, and other metals of interest using a field portable XRF analyzer. Eighteen confirmation samples also were collected for laboratory analysis of TAL metals.

(Additional details are provided in Section 12 of the ERT report, included as Appendix F of this RI Report.)

4.5.15 Analysis, Validation, and Data Management

Field and laboratory analysis, data validation, and data management were performed in accordance with the QAPP (Lockheed Martin SERAS, 2013b). Ten laboratories, including an onsite ERT/Lockheed Martin SERAS XRF laboratory, a Contract Laboratory Program (CLP) laboratory, the EPA Region 9 Laboratory, ERT/Lockheed Martin SERAS inorganic laboratory, and Lockheed Martin SERAS subcontracted laboratories were utilized to meet the analytical objectives for this project. Field measurements (including geospatial data and XRF data) and analytical results were imported to the

Scribe database. Data from the 2013 to 2015 data gap investigation were combined with data from EPA and its contractors and consolidated into a comprehensive database.

(Additional information on the analyses, data validation, and data management is presented in Section 13 of the ERT report, included as Appendix F of this RI Report.)

4.5.16 Surveys

Lockheed Martin SERAS subcontracted an engineering firm (Granite Basin Engineering, Inc., Prescott, Arizona) to perform ground survey work, which included the following:

- Horizontal and vertical survey measurements were made of new monitoring wells and piezometers that had been installed in 2014 (see also Section 4.5.7).
- There are large cracks in the top of the primary slag pile. Survey measurements were made of the cracks to monitor potential movement and determine if the clacks are widening.
- The dimensions of the Chaparral Gulch Dam were surveyed and a number of scaled drawings were prepared in support of the stability analysis. Borehole data from 2014 were additionally used to determine the slope of the concrete on the upstream side of the dam and characteristics of the natural bedrock surface on either side of the dam (see also Section 4.5.3).
- Topographic data were acquired throughout the Smelter Tailings Swale. These data were combined with 2014 borehole data to verify the approximate depth to natural ground beneath the tailings and ultimately estimate the volume of the tailings within this area (see also Section 4.5.3).
- Channel cross sections and a longitudinal profile were surveyed in an area downstream of the Chaparral Gulch Dam to assist with a hydraulic analysis of the lower Chaparral Gulch (see also Section 4.5.10, Surface Water and Sediment Monitoring: Chaparral Gulch and Agua Fria River).

(Granite Basin's Iron King Mine Survey Report and supporting data, figures, and tables can be found in Section 14 of the ERT report, included as Appendix F of this RI Report.)

4.5.17 Support Information

Additional supporting data collected for the ERT report are summarized in this section. This section also discusses aerial imagery, topographic, and parcel data that were obtained to fill related data gaps. Supporting information in the ERT report included the following:

- Chaparral Gulch flood hazard survey prepared by Cardno, Inc., for Yavapai County
- Construction materials survey performed by Lockheed Martin SERAS to identify local offsite sources of natural materials that could be used in future Site remediation
- Humboldt Smelter stack structural condition assessment performed by Core Structure Group, LLC (subcontractor to Lockheed Martin SERAS)

(Additional data and information on the Chaparral Gulch flood hazard survey, construction materials survey, and Humboldt Smelter stack assessment are provided in a directory entitled "Support Information," in the ERT report, included as Appendix F of this RI Report.)

4.5.17.1 Chaparral Gulch Flood Hazard Survey

Cardno, Inc., prepared the Chaparral Gulch Flood Hazard Study in 2014 for the Yavapai County Development Services, Flood Control District (Cardno, Inc., 2014; refer to Appendix F). The purpose of the study was to identify the watershed that drains toward Chaparral Gulch and its tributaries, estimate the 10-year, 50-year, 100-year, and 500-year flows, and prepare a floodplain delineation on the approximately 5-mile-long section of Chaparral Gulch that is located in the unincorporated areas of Yavapai County. This study was not contracted by EPA but was performed concurrent to the data gap investigation and helped fill the identified data needs (CH2M, 2013). These data will be used in the development and evaluation of remedial alternatives in the FS, including the evaluation of erosion potential of tailings and the conceptual design of potential conveyance channels.

The method selected for use in this study was the regional regression methodology in accordance with criteria outlined in Level 2 procedures of the Arizona Department of Water Resources, Flood Warning and Dam Safety Section, Delineation of Riverine Floodplains and Floodways in Arizona. These Level 2 procedures are based on the USGS regional regression equations. The USGS National Flood Frequency Program Version 5.1, which utilizes the regional regression equations, was used to calculate the peak flows. The U.S. Army Corps of Engineers Hydrologic Engineering Center's HEC-RAS Software Version 4.1.0 was used to model the riverine hydraulics for this study (Cardno, 2014).

4.5.17.2 Construction Materials Survey

The objective of the Construction Materials Survey was to identify local offsite sources of natural materials that could be used in future site remediation (for example, erosion protection, low permeability soil cover, drainage material, and engineered fill) (Lockheed Martin SERAS, 2013a). Suppliers local to the Site were contacted to determine the types of products that were available. Materials of interest included riprap (quarried rock), angular gravel, bank-run gravel, pea gravel, sand (various grain sizes), clayey and noncohesive backfill materials, road base material (mixed soil and gravel), and organic topsoil. Supplier names, phone numbers, addresses, and available products were documented (refer to Appendix F) and will be used in the development of alternatives in the FS.

4.5.17.3 Smelter Stack Assessment

Lockheed Martin SERAS subcontracted Core Structure Group, LLC to perform a structural condition assessment of the Humboldt Smelter stack in 2013 (Core Structure Group, LLC, 2013; refer to Appendix F). The investigation was limited to a visual review of the major structural components of the building during site visits in December 2013. The assessment concluded that the structure is unstable, and total or partial collapse of the structure could occur. The smelter tower is particularly susceptible to collapse due to its height and exposure to wind forces (Core Structure Group, LLC, 2013). The assessment included delineation of a safety perimeter around the structure.

4.5.17.4 Aerial Imagery, Topographic, and Parcel Data Collection

Aerial imagery, topographic, and parcel data were obtained to assist with figure generation, to estimate the volume of mine wastes, and to identify parcels where property access was required as part of the sampling plan. These data also will be used during the development and evaluation of remedial alternatives in the FS (for example, in site grading plans, stormwater routing assessments, and waste consolidation and capping evaluations). The following data sources were used, in addition to the topographic and survey data discussed in the previous subsections:

- Granite Mountain Survey provided Lockheed Martin SERAS with aerial imagery and 2-foot topographic contour coverage data from the Yavapai County GIS Department (2013). These data will be used to support the conceptual design of potential remedial alternatives in the FS.
- Yavapai County provided Lockheed Martin SERAS with parcel data for identifying property boundaries, physical addresses, and ownership information. These data were used to request access prior to surface soil sampling.
- CH2M obtained imagery from the U.S. Department of Agriculture (USDA)-Farm Service Agency Aerial Photography Field Office (USDA, 2015) (used for RI figure generation).
- CH2M obtained 2015 Google Earth imagery (used for RI figure generation).

SECTION 5

Physical Site Characteristics

This section summarizes the physical characteristics of the Site including the physiographic setting, meteorology, surface water features, geologic conditions and soils, hydrogeology, ecological habitat areas, and demographics/land use. This information forms the basis for evaluating the nature and extent of contaminated media at the Site. It also provides the basis for evaluating the fate and transport of that contamination, and potential exposure pathways.

5.1 Physiographic Setting

The Site is located in a mountainous region in central Arizona at the southeastern end of Lonesome Valley in Yavapai County (Figure 5-1). The northern portion of Lonesome Valley is drained by the Verde River and its tributaries within the Verde watershed. The southern portion of Lonesome valley is drained by the Agua Fria River and its tributaries within the upper portion of the Agua Fria watershed. A surface water divide located along Arizona State Highway 89 separates the two drainage systems (Figure 5-1). The Agua Fria River joins the Gila River near Phoenix, about 85 miles south of the Site, while the Verde River flows into the Salt River.

Lonesome Valley is bordered on the west by the Bradshaw Mountains and on the east by the Black Hills. (Figure 5-1). The two ranges converge near the Town of Dewey-Humboldt.

As shown on Figure 5-2, topography over most of the area west of the Agua Fria River slopes generally east/southeast toward the river, with localized ridges and valleys that trend northwest to southeast. Humboldt Proper, just north of the former Humboldt Smelter and west of the Agua Fria River, lies at elevations between approximately 4,500 and 4,600 feet. A prominent northwest to southeast trending ridge is located northwest of Humboldt Proper and north of the former Iron King Mine property, west of Highway 69. This ridge rises to elevations exceeding 4,800 feet west of Highway 69. East of the Agua Fria River, the topography rises eastward toward the highlands of the Black Hills. The terrain south of the Town of Dewey-Humboldt is rugged and steep.

The former Iron King Mine property is situated along the east flank of Spud Mountain, a peak on the east side of the Bradshaw Mountains, along a topographic divide between the Galena Gulch and Chaparral Gulch arroyos (Figure 5-2), which convey stormwater runoff east/southeast to the Agua Fria River (Figure 5-2). Surface elevations at the former Iron King Mine property range from approximately 4,600 to 4,800 feet.

The majority of the former Iron King Mine property is located within the Chaparral Gulch watershed, which is bordered on the north/northeast by the prominent ridge described above. Topography over most of the property slopes northeastward toward the Chaparral Gulch. Approximately 200 feet of topographic relief occurs between Iron King Mine (at the former Mineworks area) and Chaparral Gulch.

The former Humboldt Smelter property is located approximately 3,000 feet southeast of the former Iron King Mine property on a plateau overlooking the Agua Fria River (Figure 5-2). The surface elevation over most of the property ranges from approximately 4,560 to 4,600 feet. The southwestern half of the property drains to Chaparral Gulch, which crosses the western portion of the site and has cut a steep canyon through volcanic rocks in this area. Approximately 160 feet of topographic relief locally occurs between the Smelter Plateau and the Chaparral Gulch channel. The Chaparral Gulch Dam was constructed across Chaparral Gulch to impound tailings and alluvium derived from upstream areas, forming the Tailings Floodplain that partially fills this canyon.

The northeastern half of the former Humboldt Smelter property drains toward the Agua Fria River, which flows along the eastern portion of the Humboldt Smelter. The Agua Fria River has incised a steep-walled canyon though volcanic rocks and underlying bedrock in this area. Approximately 200 feet of topographic relief occurs between the Humboldt Smelter Plateau and the Agua Fria River near its confluence with Chaparral Gulch.

5.2 Meteorology

The Site location is characterized by cool but mild winters and hot summers. The closest meteorological station is located approximately 15 miles west-northwest of the Site at the Prescott Municipal Airport (Ernest A. Love Field) on the northern side of the Bradshaw Mountains. The elevation of the airport and the Site are similar, and meteorological data at the airport are expected to be generally representative of Site conditions. Figure 5-3 illustrates the seasonal temperature and precipitation trends for the Prescott Municipal Airport station.

The annual average low and high temperatures for the period of record (1948 to 2015) are 40 degrees Fahrenheit (°F) and 70°F, respectively. Seasonal fluctuations in temperature are about 40°F with the lowest temperatures occurring in December and January (average high of approximately 50°F) and the highest temperatures occurring in July (average high of approximately 90°F). Diurnal temperature swings are on the order of 30°F. Average low temperatures are below freezing December through March.

The average annual precipitation for the period of record is approximately 13 inches. Precipitation occurs throughout the year, with approximately 40 percent of the annual total in July and August when monsoonal thunderstorms are common. Occasional snowfall occurs in the winter months.

A meteorological station was installed at the former Iron King Mine property to monitor wind speed and direction at the Site from August 2008 to August 2009 (EA, 2010). The meteorological station was located in the southeastern portion of the NAI Operations area, near sample location AIK-02 (see Section 4, Figure 4-6). Figure 5-4 shows windrose diagrams for the monitoring period. Windrose diagrams are radial plots that summarize the distribution of wind direction and speed at a particular location. These diagrams indicate that the wind directions are variable at the Site, but for most of the year, the prevailing wind is from the south and southeast. During the months of November, December, and January, the prevailing wind direction was from the northwest.

The average wind speed was 6 miles per hour (mph) (EA, 2010), or 2.7 meters per second, during the monitoring period, and commonly exceeded 5 meters per second (Figure 5-4). The location of this meteorological station was 100 to 150 feet lower in elevation than the upper portion of the MTP. Average wind speeds could be greater than those measured at higher elevations on the Site or during water years with a greater frequency of storm events or higher intensity storm events.

5.3 Surface Water Hydrology

The Site is located in the upper portion of the Agua Fria watershed (Upper Agua Fria watershed). This surface water system is characterized by ephemeral or intermittent streams or arroyos that discharge snowmelt and rainfall from the surrounding Black Hills and Bradshaw Mountains. The Agua Fria River is the primary surface water feature in the valley. Most reaches of the Agua Fria are ephemeral. However, perennial base flow conditions occur in the river near Humboldt Proper north of the Site, where basin fill deposits (Hickey Formation aquifer units) pinch out against the basement rocks and groundwater discharges from these units to the Agua Fria River channel (Corkhill and Mason, 1995). This baseflow likely occurs along the wooded areas of the Agua Fria River channel upstream of the former Humboldt Smelter property (Figure 5-5). The perennial reach of the Agua Fria River continues for approximately 12 miles south of its confluence with Chaparral Gulch (ADEQ, 2006).

Locally important secondary drainages include the Chaparral Gulch and Galena Gulch arroyos, which drain the eastern flank of the Bradshaw Mountains to the Agua Fria River. Chaparral Gulch passes by the former Iron King Mine property to the northeast, and then crosses northwest to southeast across the former Humboldt Smelter property; it discharges to the Agua Fria River just downstream of the former Humboldt Smelter property (Figure 5-5). Galena Gulch transects the southwestern portion of the former Iron King Mine property and discharges to the Agua Fria River approximately 1 mile south of the former Humboldt Smelter property (Figure 5-5).

As shown on Figure 5-5, two drainages carry the name "Galena Gulch." In ADEQ mapping, the drainage running adjacent to the Iron King Mine property is an unnamed tributary, and the longer drainage to the southwest is identified as Galena Gulch (ADEQ, 2016). In this RI, the tributary adjacent to and crossing the former Iron King Mine property is named Galena Gulch for consistency with previous EPA Site documents. The two drainages intersect just upstream of the confluence with the Agua Fria River.

Chaparral and Galena Gulches only flow during infrequent episodic high rain events, with the exception of continuous groundwater seepage that occurs in lower Chaparral Gulch. These gulches are classified as both "intermittent" and "ephemeral" drainages in previous Site documents. For example, ADEQ classifies Galena Gulch as an "ephemeral" drainage, which is defined as a drainage that is at all times above the water table and flows only in direct response to precipitation. In this RI, Chaparral and Galena Gulches are classified as "intermittent drainages," consistent with the USGS National Hydrography Dataset (USGS, 2014). Intermittent drainages are dry during part of the year; however, they may also have areas of saturated soil, persistent wetland vegetation, and/or areas of ponded water indicating that a spring or groundwater supports the flow regime (such as occurs in lower Chaparral Gulch).

The hydrology of the Agua Fria River, Chaparral Gulch, and Galena Gulch is discussed in the following sections, followed by a discussion of watershed land use and surface water use.

5.3.1 Agua Fria River

The Agua Fria River flows through Lonesome Valley and south across central Arizona to its confluence with the Gila River near Phoenix. The entire Agua Fria River watershed encompasses approximately 2,800 square miles. The Site is located within the Upper Agua Fria watershed in the Big Bug Creek–Agua Fria subwatershed (USGS Hydrologic Unit Code H1507010202; 324 square miles) (NRCS, 2007a).

In the vicinity of the Site, the Agua Fria River flows along the eastern portion of the former Humboldt Smelter property in a narrow canyon incised into middle (volcanic) Hickey Formation and the underlying Precambrian bedrock (refer to Section 5.4 for a discussion of geologic conditions). Although the Agua Fria River is intermittent along most stretches, perennial flow conditions occur from a few miles north of the Site to well past the Site. It receives stormwater from the northern reaches of the Agua Fria River, where farming, livestock, and point sources (for example, wastewater treatment effluent) enter. Adjacent to the Site, stormwater enters the Agua Fria River from residential areas to the east and the former Humboldt Smelter property to the west. During high rain events, the Agua Fria River receives considerable flow from Chaparral Gulch. The Agua Fria River also receives surface water from the Galena Gulch during high rain events.

A USGS gaging station (09512450) is located in the Agua Fria River approximately 0.75 mile downstream from the Site between the river's confluences with Chaparral Gulch and Galena Gulch (Figure 5-5). Stream flow data are available for Station 09512450 for water years 2000 to 2014. During this period, the mean monthly discharge ranged from approximately 10 cubic feet per second (cfs) recorded for February to approximately 1 cfs recorded for June (Table 5-1). Annual average discharge for this period of record was approximately 5 cfs. The long-term average baseflow contribution from the gaining reach upstream of this station has been estimated at 1.5 cfs (Wilson, 1988). The maximum discharge observed for the period of record was 11,900 cfs on September 8, 2002.

Comparison of the average monthly flows in the Agua Fria (Table 5-1) and the average monthly precipitation at Prescott Airport (Figure 5-3) indicates that while the highest average flows on the Agua

Fria River are in the months of January and February, the highest monthly average precipitation at Prescott Airport occurs in July and August. This difference in timing may be, in part, due to the relatively short flow record at the USGS gage (15 years) and the highly variable nature of the precipitation pattern in the region both temporally and spatially. The precipitation record is 67 years long and is likely to be representative of average precipitation conditions at the Prescott Airport. In January and February of 2005, very large flows in the Agua Fria were recorded due to large storm events. These January and February storms in this single year influence the calculated average monthly flows substantially for these months. The relatively short flow record for the USGS gage on the Agua Fria should be considered when these data are used in future evaluations.

Figure 5-6 shows the 100-year flood plain along the Agua Fria River near the Site. Site-related materials along the Agua Fria River, including portions of the former Humboldt Smelter property slag pile and the Agua Fria Tailings Pile, are located within its 100 year-flood plain. These areas are likely to be inundated and potentially eroded during an extreme flood event.

5.3.2 Chaparral Gulch

The Chaparral Gulch watershed comprises an area of approximately 9-square miles (Figure 5-6). The headwaters of the watershed originate west of the former Iron King Mine property in the foothills of the Bradshaw Mountains within the Prescott National Forest (Figure 5-5). Tributaries to Chaparral Gulch consist entirely of unnamed ephemeral washes (Lockheed Martin SERAS, 2015). Major portions of the former Iron King Mine property and former Humboldt Smelter property lie within the Chaparral Gulch watershed (Figure 5-6).

Chaparral Gulch flows southeast through the northern portion of the former Iron King Mine property, across the former Humboldt Smelter property, and into the Agua Fria River just downstream of the former Humboldt Smelter property (Figure 5-6). The main channel of Chaparral Gulch slopes easterly at an average gradient of approximately 4 percent (Lockheed Martin SERAS, 2015). Gradients approaching or even exceeding 10 percent are common along sections of the gulch, especially downstream of the Chaparral Gulch Dam on the former Humboldt Smelter property (Lockheed Martin SERAS, 2015).

As discussed in greater detail in Section 2.1, the impounded area upstream of the dam (termed Tailings Floodplain) is filled with tailings derived from impoundment failures and historical discharges from both the former Iron King Mine property and the former Humboldt Smelter property, as well as sediment derived from upstream areas.

Stream stage measurements were collected at two locations approximately 70 feet apart along the lower Chaparral Gulch downstream of the Chaparral Gulch Dam as part of the ERT Data Gap RI (Lockheed Martin SERAS, 2015); see the “EPA Chaparral Gulch Gaging Station” on Figure 5-6. Pressure transducers were installed in standpipes, and the channel profile and cross sections were surveyed at both locations. The water levels were monitored during the period of early July through late October 2014. Flows in Chaparral Gulch were estimated from the water elevation measurements using channel topography and estimates of channel roughness, in accordance with ASTM International (ASTM) Method D5130. The calculated peak flows range from 4 to 290 cfs (Table 5-2). Appendix F includes detailed information of the channel profiles, stage measurements, and calculations used to determine flows in the gulch.

The peak flows correspond to the general timing of seasonal monsoonal thunderstorms in the area. Daily precipitation for the peak flow dates recorded at the Prescott Municipal Airport (Ernest A. Love Field) station range from 0.01 inch to 1.53 inches. Because of the variability of rainfall intensity for thunderstorm events over even small distances, the rainfall amounts measured in Prescott (which is approximately 15 miles from the Chaparral Gulch Gaging Station) do not necessarily represent the actual rainfall received in Chaparral Gulch.

Figure 5-6 shows the 100-year flood plain along Chaparral Gulch in the vicinity of the Site. The Tailings Floodplain behind the dam on the former Humboldt Smelter property, the lower Chaparral Gulch tailings deposit, and the Agua Fria Tailings Pile are all within the 100-year flood plain and could be inundated and potentially eroded during an extreme flood event.

The estimated discharges for Chaparral Gulch at the State Highway 69 culvert (just downstream of the former Iron King Mine property) and at its confluence with the Agua Fria River for a range of return periods are summarized in Table 5-3. These return flows were calculated as part of the 2014 *Chaparral Gulch Flood Hazard Study* (Cardno, Inc., 2014) (see Section 4.5 and “Support Information” in Appendix F). The 100-year return flow in the vicinity of the Site was estimated to be approximately 5,000 cfs. At this flow rate, estimated velocities in the Chaparral Gulch main channel in the vicinity of the Site would range from 3.4 to 19 feet per second based on the *Chaparral Gulch Flood Hazard Study*. These flows would readily erode sand and gravel in many reaches of the gulch. Cobble-sized material could be transported as bed load at the upper end of this velocity range.

5.3.3 Galena Gulch

Galena Gulch is a small intermittent tributary to the Agua Fria River. It flows from northwest to southeast and has a total drainage area of approximately 10.4 square miles (Figure 5-5). Figure 5-7 shows the detail of the area where Galena Gulch passes through and past the former Iron King Mine property. Galena Gulch originates just west of the former Iron King Mine property and flows through the former Mineworks and former Fertilizer Plant area. Galena Gulch then flows south/southeast before ultimately joining the Agua Fria River approximately 1 mile downstream from the former Humboldt Smelter property. No flow monitoring has been conducted on Galena Gulch.

5.3.4 Watershed Land Use

The Agua Fria River watershed land use is mostly rangeland with a mixture of cropland and urban development. In the area of the Site, cropland is limited to a strip of land that is north of Humboldt Proper, west of the Agua Fria River, and east of Highway 69 (discussed further in Section 5.7.2). Forestlands exist within the watershed at higher elevations in the Prescott National Forest. The Prescott National Forest is 1.25 million acres. Roughly half of the area lies west of the Town of Dewey-Humboldt and includes the Bradshaw Mountains; the other half of the forest lies east of the town and includes the Black Hills (U.S. Forest Service, 2016).

There are 1,061 mineral extraction mines recorded with the Office of the Arizona State Mine Inspector in the overall Agua Fria watershed, with the most common ore classifications being gold, copper, and silver (Arizona NEMO, 2006; NRCS, 2007a). There are 293 mines in the Big Bug Creek–Agua Fria subwatershed, in which the Site resides; this is the highest number of mines in any of the Agua Fria subwatersheds (Arizona NEMO, 2006).

5.3.5 Surface Water Use

Most of the flow in the Agua Fria River upstream of the Site consists of effluent from the Prescott Valley Wastewater Treatment Plant. The designated uses of surface water in the reach of the Agua Fria River near the Site are domestic water source, full-body contact (swimming), fish consumption, agricultural irrigation, agricultural livestock watering, and aquatic and wildlife (warm water) (ADEQ, 2009).
No drinking water intakes are known to exist in the Agua Fria River within 15 miles downstream of Chaparral Gulch (ADEQ, 2006). In fact, as of 2007, there were no reported surface water diversions for municipal, industrial, or agricultural use in the Agua Fria River Basin (Arizona Department of Water Resources, 2009, Table 5.1-8).

ADEQ does not specify designated uses for Chaparral Gulch. However, the aquatic and wildlife (warm water), full-body contact, and fish consumption standards would apply to Chaparral Gulch as an unlisted tributary that is an intermittent surface water and is below 5,000 feet in elevation (ADEQ, 2009).

ADEQ specifies the designated uses of Galena Gulch as aquatic and wildlife (ephemeral), partial-body contact (wading), and agricultural livestock watering (ADEQ, 2009). It is possible that this designation refers to the other Galena Gulch further to the south of the former Iron King Mine property ("Galena Gulch [ADEQ]" on Figure 5-5). In ADEQ mapping, the tributary located near the former Iron King Mine property (referred to as Galena Gulch in this RI Report) is an unlisted tributary (ADEQ, 2016).

5.4 Geologic Conditions and Soils

Lonesome Valley is part of a structural basin that extends from the Town of Dewey-Humboldt northward into Chino Valley (Wilson, 1988). The basin was formed by vertical displacement along high angle faults that border the Bradshaw Mountains to the west and the Black Hills to the east. The basin fill consists of Tertiary volcanic and sedimentary rocks that were deposited on Precambrian metamorphic basement rocks. A veneer of Quaternary alluvium occurs as a piedmont area and within active drainages.

A series of northeast-trending Tertiary-aged normal faults are interpreted to occur in the Site area based on discontinuities in bedrock topography observed during the ERT data gap drilling program (Lockheed Martin SERAS, 2015). Figure 5-8 illustrates the stratigraphic column, providing a description of the regional geologic units, their age, and their stratigraphic position. Figure 5-9 shows the distribution of the regional geologic units in the Site vicinity. Figure 5-10 illustrates the geology of the Site area in cross section. The following subsections describe the relevant geologic units in the area of the Site.

5.4.1 Precambrian Bedrock Units and Mineralization

The Precambrian Iron King Volcanics (IKV) and Spud Mountain Series (SMS) comprise the basement rocks in the Site vicinity (Figures 5-8 and 5-9). IKV and SMS are metamorphosed to greenschist facies and have well-developed, steeply dipping foliation that trends to the northeast (Krieger, 1965).

IKV are composed of massive metamorphosed andesite flows that crop out south of the Iron King Mine and extend eastward beneath the overlying Tertiary Hickey Formation toward the Agua Fria River (Figures 5-9 and 5-10).

The SMS is characterized by interbedded pelitic and tuffaceous metasediments, metatuffs, metamorphosed basalt, and andesite flows. These rocks crop out west of the former Iron King Mine property, near the eastern boundary of the former Humboldt Smelter property, and in uplands farther east of the Agua Fria River. The SMS locally includes thin and laterally discontinuous beds of oxide-facies iron formation, impure marble, metachert, and silicified felsic metavolcanic rocks, which crop out east of the Agua Fria River (east of the former Humboldt Smelter property boundary). In addition, gabbroic rocks occur in the SMS south of the former Humboldt Smelter property (Figure 5-9).

Massive sulfide vein deposits locally occur within the SMS and were the target of mining operations at the former Iron King Mine property. Figure 5-9 shows the surface exposure of the Iron King Mine ore body. As shown on Figure 5-10, the ore body within the SMS is narrow and has a nearly vertical orientation. Pyrite (FeS_2) is the dominant sulfide mineral. The primary ore minerals include sphalerite ($[Zn,Fe]S$) and galena (PbS). Other sulfide minerals present in the deposit include silver-bearing tennantite $[(Cu, Fe)_{12}As_4S_{13}]$, arsenopyrite ($FeAsS$), and chalcopyrite ($CuFeS_2$).

Although other mineralized deposits occur in the region, the ore body exploited at Iron King Mine is somewhat unique. Regional important mineralization includes Precambrian gold-quartz and late Mesozoic or Early Tertiary gold and silver vein deposits (Krieger, 1965). Although these deposits can contain pyrite, arsenopyrite and other sulfides, they have limited lead and zinc sulfide mineralization.

Massive lead-zinc sulfide deposits similar to that exploited by former Iron King Mine operations do not occur elsewhere in the region (Krieger, 1965).

5.4.2 Tertiary Hickey Formation

Basin fill deposits of the Tertiary Hickey Formation overlie the Precambrian basement rocks (Figures 5-8 and 5-10). The Hickey Formation consists of interbedded basalt flows, fanglomerate, mudflow, and tuffaceous materials (Krieger, 1965). It is subdivided into upper, middle, and lower members in the Site area based on stratigraphic relationships observed during the EPA data gap investigation (Lockheed Martin SERAS, 2015). Please note that the upper and lower members of the Hickey Formation ("Hunc" and "Hcgl," respectively) are combined in the regional mapping shown on Figure 5-9.

The upper member of the Hickey Formation (Hunc on 5-10) is interpreted as a sequence of overlapping alluvial fan deposits (fanglomerates). These basin fill deposits consist of unconsolidated, poorly sorted silt, clay, sand, and gravel. The upper fanglomerate member of the Hickey Formation is exposed over a wide area of the Site including the former Iron King Mine property, the northern portion of the former Humboldt Smelter property, and the Town of Dewey-Humboldt. It is approximately 200 feet thick beneath the former Iron King Mine property, where it was deposited on the Precambrian bedrock, and it pinches out against the middle and lower Hickey members to the east and southeast (Figures 5-9 and 5-10).

The middle member of the Hickey Formation ("Hbslt" and "Hash" [Thab] on Figure 5-10) consists of basaltic flows, ash, and cinders, which commonly occur at the base of the unit. Basalt flows (Hbslt/Thab on Figure 5-9) crop out at the former Humboldt Smelter property, northeast of the former Humboldt Smelter along the Agua Fria River, and southwest of the Humboldt Smelter on the plateau above the Agua Fria River. The flows are in excess of 100 feet thick beneath the former Humboldt Smelter property and pinch out in the subsurface to the west (Figure 5-9). Ash and cinders locally occur in the subsurface below the basaltic flows. The thickest accumulation of ash and cinders encountered during the EPA investigations (approximately 40 feet), was encountered at a depth of approximately 140 feet bgs in well MW-12D, located north of the former Humboldt Smelter property (Figures 5-9 and 5-10). Remnants of a cinder cone that appears to be the source of these volcanic deposits is visible near the west side of the Humboldt Smelter property.

The lower member of the Hickey Formation (Hcgl on Figure 5-10) underlies the Hickey volcanics. It consists of poorly sorted conglomerate with discontinuous gravel layers and is locally cemented with a calcareous matrix. This unit crops out along the western side of the canyon cut by the Agua Fria River, south of the former Humboldt Smelter property. It occurs in the subsurface below much of the former Humboldt Smelter property, but pinches out to the west against the middle and upper Hickey units (under the east side of the MTP) (Figure 5-10).

5.4.3 Quaternary Alluvium

Quaternary alluvial deposits occur within the active stream and river channels in the Site area. These deposits include sand, gravel, and silt consisting of reworked Hickey Formation and alluvium derived from the highlands surrounding Lonesome Valley. In addition to native alluvial materials, historical impoundment failures at the former Iron King Mine property and the former Humboldt Smelter property have released tailings into Chaparral Gulch, where they have been reworked and redeposited by stormwater flow. Figure 5-9 shows the areas with larger accumulations of Quaternary alluvium in the Site vicinity, which include the Agua Fria River channel north of the site, and the Chaparral Gulch on the western portion of the former Humboldt Smelter property. Although not shown on this map, a thin veneer of Quaternary alluvium also occurs in Galena Gulch, other portions of Chaparral Gulch, and other ephemeral streams in the Site vicinity.

As part of the data gap investigation, ERT implemented a drilling program to characterize alluvium deposits in Chaparral Gulch upstream of the Chaparral Gulch Dam (Lockheed Martin SERAS, 2015). ERT identified and mapped six alluvial units, which are described below in stratigraphic order from top to bottom of the alluvial section in the gulch:

- **Uppermost Channel Deposit (UCD).** The UCD consists of brown to light brown clayey silt to fine sand with occasional pebbles. It is up to 13 feet thick (Lockheed Martin SERAS, 2015).
- **Tailings.** The tailings consist of homogeneous silty clay materials with oxidized (orange, red, or brown) and reduced (green, black, or gray) zones. The reduced tailings deposits are encountered where the unit is saturated. The tailings deposits are up to 23 feet thick (Lockheed Martin SERAS, 2015).
- **Humboldt Smelter Channel Deposit (HSCD).** The HSCD is mottled dark red to brown and consists of silt to coarse sand with some pebbles. It is interbedded with tailings, generally less than 5 feet thick, and may coalesce with the Lowermost Channel Deposit (Lockheed Martin SERAS, 2015).
- **Lowermost Channel Deposit (LCD).** The LCD occurs in the subsurface of the gulch, is mottled brown, green, and gray in color, and consists primarily of pebbly sand with occasional cobbles. It has a maximum thickness of approximately 8 feet (Lockheed Martin SERAS, 2015).
- **Brown Clay.** This unit consists of dark brown clay with very weakly developed laminae. It is up to 8 feet thick, occurs in the subsurface along the arroyo, and is exposed in the Smelter Tailings Swale (Lockheed Martin SERAS, 2015).
- **Principal Fluvial Gravels (PFG).** The PFG is mottled brown to dark green and consists of poorly sorted clayey silty gravels with some pebbles and cobbles. It occurs only in the subsurface, was deposited on underlying bedrock, and is up to 14 feet thick.

In the data gap phase of the RI, the UCD, HSCD, and LCD are interpreted to consist of mixed tailings and fluvium based on stratigraphic position, physical characteristics, and chemical characteristics (Lockheed Martin SERAS, 2015). The Brown Clay and PFG were interpreted to be native Quaternary alluvial deposits (Lockheed Martin SERAS, 2015). Section 7.2.3 presents a more detailed description these units, their distribution, and their chemical characteristics. Section 7.2.3 and Section 8 also discuss the potential sources of metals detected in these units, the sequence of their deposition, and implications regarding contaminant migration in Chaparral Gulch.

5.4.4 Soils

Two major soil types have been mapped near the Site: (1) the Balon gravelly sandy loam; and (2) the soils of the Springerville-Cabezon complex (NRCS, 2007b). Balon gravelly sandy loam is a very deep, well-drained soil that forms on mixed alluvial deposits. Locally, it develops on the upper or lower (nonvolcanic) Hickey Formation units, and therefore is the most common soil type in the area, occurring in undisturbed areas at the former Iron King Mine property, in the Town of Dewey-Humboldt, and in portions of the former Humboldt Smelter property not underlain by volcanic rocks. The Springerville-Cabezon complex consist of deep, well-drained soils that formed on alluvium derived from tuff, volcanic breccia and basalt. Locally, these soils develop on outcrops and alluvium derived from the middle (volcanic) Hickey Formation, and are found at and south of the former Humboldt Smelter property.

5.5 Hydrogeology

The Site is located in the Upper Agua Fria Groundwater Subbasin of the Chino-Prescott Valley Basin. The basin is a 28-mile-long structural basin that developed during the Tertiary Basin and Range extensional event (Krieger, 1965) filled with a complex sequence of alluvial, volcanoclastic, and volcanic deposits (Hickey Formation). The basin is bounded by faults that border the Bradshaw Mountains and Black Hills to the west and east. A groundwater divide separates the Agua Fria Groundwater Subbasin from the Little Chino Groundwater Subbasin to the north. South of this divide, groundwater flows from recharge areas along the mountain fronts of the Bradshaw Mountains and Black Hills toward the center of the Upper Agua Fria Groundwater Subbasin and then southward toward the Town of Dewey-Humboldt, where groundwater locally discharges to the Agua Fria as baseflow (Corkhill and Mason, 1995). Other areas of localized recharge include ephemeral or intermittent surface water features such as Chaparral Gulch and Galena Gulch. These sources likely fluctuate seasonally as various stream reaches alternate from gaining to losing streams. Other local sources of recharge include irrigation runoff, wastewater treatment effluent, and direct infiltration of precipitation.

5.5.1 Hydrostratigraphy

Tertiary Hickey Formation and the Precambrian basement rocks are the primary hydrostratigraphic units in the vicinity of the Site. In addition, Quaternary alluvium (a mixture of alluvium and tailings) is locally saturated beneath the Chaparral Gulch floodplain upstream of the Chaparral Gulch Dam. The water-bearing characteristics of these units are described below:

- **Quaternary Alluvium.** Unconfined groundwater conditions locally occur in the Quaternary alluvium in Chaparral Gulch upstream of the Chaparral Gulch Dam (Lockheed Martin SERAS, 2015). The PFG, UCD, and LCD contain abundant sand and gravel and can transmit water where saturated. The tailings deposits consist predominantly of clay and silt and are expected to be less transmissive than the channel units. The PFG is saturated from Third Street to the Chaparral Gulch Dam (Lockheed Martin SERAS, 2015).
- **Tertiary Hickey Formation.**
  - The upper Hickey Formation contains relatively thick zones (up to 75 feet) of low-permeability materials, interlayered with narrow intervals (less than 5 feet thick) of more permeable, water-bearing sands and gravels, forming a semiconfined groundwater zone (Lockheed Martin SERAS, 2015).
  - Where fractured, joined, or interbedded with alluvium, the Middle Hickey Formation volcanics are water bearing. Where the flows are massive and unfractured, the unit acts as an aquitard, impeding groundwater flow (Lockheed Martin SERAS, 2015).
  - The lower Hickey Formation has poorly sorted (matrix-supported) conglomerates with discontinuous but more permeable gravel layers dispersed throughout the section (Lockheed Martin SERAS, 2015). The conglomerate is locally cemented with calcareous matrix, impeding groundwater flow. In general, the gravel layers can be characterized as discontinuous semiconfined groundwater zones; however, there are isolated high yielding groundwater zones, including the unconformity with the underlying Precambrian basement rocks (Lockheed Martin SERAS, 2015).
- **Precambrian Bedrock.** Groundwater in the Precambrian bedrock occurs primarily in weathered regolith zones, where saturated, and in fractures.

Regionally, the sedimentary and volcanic units within the Hickey Formation have been combined into a single hydrostratigraphic unit for the purpose of basin-scale studies (Corkhill and Mason, 1995). A similar approach has been implemented for the purpose of evaluating groundwater flow conditions at the Site.

5.5.2 EPA Groundwater Monitoring Well Network

A total of 26 groundwater monitoring wells were installed between 2008 and 2014 as part of EPA's RI, including:

- 12 wells screened in the Hickey Formation
- 5 wells completed in the Quaternary alluvium/tailings of Chaparral Gulch
- 5 wells screened in the MTP
- 3 wells screened in the Precambrian IKV
- 1 well screened in the Precambrian SMS

Figure 5-11 shows the locations of these monitoring wells along with the piezometric surface based on water levels measured in October 2014. Table 5-4 summarizes the construction details of the wells. Many of the shallower wells were installed by sonic drilling methods and continuously cored, allowing water-bearing zones to be identified and the monitoring well to be screened in these zones. Most of the deeper wells were completed using a combination of sonic and downhole hammer drilling methods.

Water level measurements collected by EPA are presented in Table 5-5. EPA has collected water level data from select wells in 2008, 2009, 2010, 2012, and 2014. The latest measurements (October 2014) were collected from the full network and were used to evaluate groundwater flow directions and gradients (as illustrated on Figure 5-11). In addition to manual water level measurements, ERT instrumented four of the five wells completed in the alluvium of Chaparral Gulch and three wells completed in the MTP with transducers to assess groundwater responses to rainfall.

The depth to groundwater in the Site vicinity varies from less than 10 feet bgs to more than 100 feet bgs because of the large topographic relief in the area.

5.5.3 Groundwater Flow Directions and Gradients

For the purpose of evaluating groundwater levels and gradients, the monitoring well network was divided into three groups based on the hydrostratigraphic unit screened by the wells. Figure 5-11 shows the interpreted piezometric surface contours for wells screened in the Quaternary alluvium (in Chaparral Gulch), Tertiary Hickey Formation, and Precambrian bedrock, using October 2014 data. The wells screened in the MTP have had minor groundwater accumulations or have been dry.

Saturated conditions occur in the Quaternary alluvium within Chaparral Gulch upstream of the dam. Chaparral Gulch has incised a fairly steep channel feature that has been partially filled with alluvium and tailings derived from upland areas (the Tailings Floodplain). The saturated thickness of these deposits locally exceeds 20 feet near the Chaparral Gulch Dam. Groundwater flow occurs along the channel to the dam, where it appears to discharge as seepage beneath or around the dam abutments. The hydraulic gradient in these alluvial deposits is approximately 0.0034 foot per foot (ft/ft).

Groundwater flows from west to east in the Hickey Formation at the Site with a gradient of approximately 0.038 ft/ft and is interpreted to converge toward the gaining reach of the Agua Fria, where groundwater discharges to the river as baseflow (Figure 5-11). Within the Chaparral Gulch floodplain, the piezometric surface elevation in the Hickey Formation is similar to that of the alluvium (Figure 5-11). At MW-2S, which is screened in the Hickey Formation, the piezometric surface is approximately 4,475 feet mean sea level (msl), which is slightly above the piezometric surface elevation in nearby alluvium monitoring well CHF-MW-03 (4,467 feet msl). In addition, the piezometric surface elevation in MW-2S is above the base of saturated alluvium in the Chaparral Gulch channel near the well. Although not definitive (there are no collocated alluvium and Hickey Formation monitoring wells), these conditions suggest there may be local groundwater interaction between the two units, with groundwater recharge to or groundwater discharge from the Hickey Formation depending on groundwater levels in each unit.

Bedrock monitoring wells were installed at three locations, all west of the Agua Fria River (Figure 5-11). Although local groundwater flow variations in the fractured bedrock may occur because of fracture orientation and the degree of interconnection among fractures, the existing bedrock monitoring wells are sufficient to establish a generalized groundwater flow direction and gradient. Based on data collected from the EPA monitoring wells, the groundwater flow direction in the fractured bedrock is to the east, with a hydraulic gradient of approximately 0.054 ft/ft. The observed groundwater flow direction is consistent with the general topography of the area. Although there are no monitoring wells east of the Agua Fria River, groundwater flow also likely mirrors topography in this area and flows westward toward the Agua Fria River.

Three collocated monitoring well pairs screened within the Hickey Formation and Precambrian bedrock were installed between 2008 and 2014 as part of the various phases of EPA's RI (Table 5-4). Vertical gradients at these locations are downward and range from 0.044 to 0.28 ft/ft. Comparable vertical gradients occur between the shallow and deep Hickey Formation at collocated wells MW-12S and MW-12D. Although vertical gradients are downward at these well locations, groundwater discharges from the Hickey Formation to the Agua Fria River are expected to occur in the gaining reach of the river north of the Humboldt Smelter, and consequently, upward vertical gradients are expected to occur in that area as well.

5.5.4 Groundwater Response to Rainfall

ERT installed pressure transducers to collect continuous water level measurements from four alluvium monitoring wells in Chaparral Gulch (CHF-MW-01, CHF-MW-02, CHF-MW-03, and STS-MW-04I) and three monitoring wells completed in the MTP (MTP-MW1, MTP-MW2, and MTP-MW3) (Lockheed Martin SERAS, 2015). Figure 5-11 shows the location of these monitoring wells. Continuous water level measurements were collected from these wells from June 20 to October 24, 2014. Hydrographs for the wells were plotted with the rainfall record for the Prescott Municipal Airport for the same time period to evaluate the groundwater level response to rainfall (Lockheed Martin SERAS, 2015) (Figure 5-12).

The data collected show that groundwater levels in CHF-MW-01, CHF-MW-02, CHF-MW-03, and STS-MW-04I vary in response to precipitation events (Lockheed Martin SERAS, 2015) (Figure 5-12). MTP-MW1, MTP-MW2, and MTP-MW3 remained dry during the entire monitoring period. Intermittent rain began in early July, but the water levels in the monitoring wells declined by approximately 3 feet until mid-August, when monsoon rains began (Figure 5-12) (Lockheed Martin SERAS, 2015). Groundwater levels in the wells responded rapidly to the more intense rainfall, increasing up to 5 feet (CHF-MW-01) by August 21, 2014. The rains continued and by October 24, 2014, groundwater levels in CHF-MW-02, CHF-MW-03, and STS-MW-04I gradually increased by an additional 3 feet. Groundwater levels in CHF-MW-01, however, peaked and then declined into late September, dropping by approximately 2.5 feet.

CHF-MW-01 is located about 200 feet upstream of the Chaparral Gulch Dam. The top of the dam has an elevation of 4,461 feet msl, which is 3 feet below the peak groundwater level elevation that was recorded in CHF-MW-01 (Figure 5-12) (Lockheed Martin SERAS, 2015). The declining water level in CHF-MW-01 occurred as groundwater levels in the upgradient wells (CHF-MW-02, CHF-MW-03 and STS-MW-04I) increased. Given the proximity of CHF-MW-01 to the dam, this pattern suggests that as the groundwater mound in the alluvial fill of the gulch increased, possibly caused by infiltration of surface water flow within the Chaparral Gulch channel, groundwater discharge near the dam also increased, resulting in a decline in groundwater levels in CHF-MW-01 (Lockheed Martin SERAS, 2015). The groundwater discharge may have occurred as leakage under the dam, or surface seepage, or a combination of these mechanisms.

5.5.5 Groundwater Use

Groundwater uses within the Upper Agua Fria Groundwater Subbasin include domestic supply, public supply, irrigation, and industrial uses. Two water companies service portions of Dewey-Humboldt, but the majority of the population relies on individual domestic wells for drinking water (Town of Dewey-Humboldt, 2009). Wells completed in the Hickey Formation and Precambrian bedrock are used for potable supply.

In 2014, Humboldt Water Company served water to approximately 330 households in south-central Dewey-Humboldt (Arizona Corporation Commission Utilities Division, 2015). The Humboldt Water Company is completely dependent on groundwater to meet water demand, and produces groundwater from two supply wells located approximately one-half mile north of the Humboldt Smelter site (see the locations of GW-533639 and GW-623784 on Figure 5-13). These wells are completed to depths of 305 and 170 feet bgs, respectively, and based on interpretation of boring logs for these wells, they are screened in the Hickey Formation. The well yields range from 40 gpm to 95 gpm (Arizona Corporation Commission Utilities Division, 2015).

Wilhoit Water Company's service area is located approximately 2 miles north of the former Iron King Mine property, north of Highway 169, near the northernmost boundary of Dewey Humboldt. The Wilhoit Water Company supplies water from two production wells to approximately 50 households (in 2006) (ADEQ, 2006). These supply wells are not shown on Figure 5-13, which only includes supply wells sampled during pre-NPL investigations or the various phases of the RI. The Wilhoit Water Company also maintains a pay-as-you-go standpipe so that individuals not connected to the water system can purchase water as needed. A large number of individuals in this area haul water from this standpipe (Town of Dewey-Humboldt, 2009).

Roughly 80 percent of the local population relies on water rights from private exempt wells (less than 35 gpm) for water supply (Town of Dewey-Humboldt, 2009). Consequently, a large number of private supply wells are located in the vicinity of the Site. Approximately 200 private supply wells are located within a 1-mile radius of the former Iron King Mine property and former Humboldt Smelter property; approximately 600 are located within a 2-mile radius of these properties (ADEQ, 2006). Figure 5-13 shows the locations of private supply wells that have coordinates available and were sampled during pre-NPL investigations or the various phases of the RI. Accurate location information and construction details are not readily available for most private wells in the Site vicinity (EA, 2010).

The northwestern portion of the Upper Agua Fria Groundwater Subbasin, including the majority of the Town of Dewey-Humboldt, is within the Prescott AMA. Areas with heavy reliance on groundwater were identified and designated as AMAs by the State of Arizona, and are subject to regulation pursuant to the 1980 Arizona Groundwater Code. The Prescott AMA covers 485 square miles in Yavapai County, although only a small portion is within the Upper Agua Fria Groundwater Subbasin. The Prescott AMA has a statutory goal of achieving safe-yield by 2025. Safe-yield refers to achieving and maintaining a long-term balance between the amount of groundwater withdrawn and the annual amount of natural and artificial recharge in the AMA. The Prescott AMA consists of two subbasins: the Little Chino to the north, and the Upper Agua Fria to the south (Arizona Department of Water Resources, 2014).

5.5.6 Regional Groundwater Quality

In general, groundwater produced from the Hickey Formation in the Upper Agua Fria Groundwater Subbasin is characterized as calcium-bicarbonate-dominant groundwater with TDS concentrations less than the secondary drinking water MCL of 500 mg/L (Wilson, 1988). Groundwater produced from Precambrian bedrock has similar characteristics but can have higher TDS and sulfate concentrations. TDS concentrations locally exceed the secondary drinking water MCLs in groundwater from both aquifer units. Nitrate and arsenic concentrations also locally exceed primary MCLs.

Nitrate concentrations in groundwater are generally low (less than 3 mg/L) in most of the Upper Agua Fria Groundwater Subbasin; however, nitrate concentrations locally exceed the primary MCL in the Dewey-Humboldt area (Towne and Freark, 2000). An examination of groundwater quality in this area by ADEQ in 1987 found that 7 of 19 sampled wells exceeded the primary MCL for nitrate, and approximately 25 percent of 116 wells in the area sampled by a community organization had nitrate levels that exceeded the MCL (Towne and Freark, 2000). The Town of Dewey-Humboldt does not have sewer mains or a wastewater treatment plant. Residents have installed septic sewer systems on their properties to serve their individual needs (Town of Dewey-Humboldt, 2009). The nitrate exceedances are suspected to be associated with older septic systems and past agricultural activities (Towne and Freark, 2000).

Ambient arsenic concentrations in groundwater locally exceed the primary MCLs in the Upper Agua Fria Groundwater Subbasin (Towne and Freark, 2000). The natural exceedance of the arsenic MCL is a consequence of Arizona’s geology, where hydrothermal mineralization, including arsenic-bearing minerals, are common. Oxidation and weathering of arsenic-bearing minerals can mobilize arsenic, which can then accumulate in groundwater. Approximately 40 percent of the domestic wells sampled by EPA during the various phases of the RI had arsenic concentrations that exceeded the MCL, including wells located far from the former Iron King Mine property and former Humboldt Smelter property (the nature and extent of contamination is discussed in Section 7). EPA, the Agency for Toxic Substances and Disease Registry (ATSDR), ADEQ, Arizona Department of Health Services, and other state and local health agencies are encouraging residents to test private well water for arsenic and lead, and if concentrations are above drinking water standards, to install a water treatment system (Arizona Department of Health Services, 2016).

Groundwater produced from the Humboldt Water Company wells has had arsenic and nitrate concentrations that exceeded the primary MCLs. Humboldt Water Company has constructed an arsenic and reverse osmosis treatment system to improve the quality of water served (ADEQ, 2015b; Arizona Corporation Commission Utilities Division, 2015; Southwestern Utility Management, Inc., 2016).

5.6 Ecological Setting

Studies characterizing the biological conditions at the Site have included a biological evaluation completed by EnviroSystems (2009), a riparian and jurisdictional wetland determination for lower Chaparral Gulch completed by WestLand Resources, Inc. (2009), and a reconnaissance-level biological survey in and surrounding the Agua Fria River riparian corridor recommended by the data gap analysis and completed by Lockheed Martin SERAS (2015). The first two studies were performed as part of the initial phase of the RI (Section 4.2.7); the third study was performed as part of the data gap phase of the RI (Section 4.5.11).

5.6.1 Habitats

The topography at the Site is characterized as steep to rolling uplands dissected by steep-walled canyons (Section 5.1). As a result of historical mining, smelting, and dross operations, large portions of the former Iron King Mine property are covered with mine tailings and waste rock, and large portions of the former Humboldt Smelter property are covered with tailings, slag, and imported dross. Historical operations have resulted in severely degraded habitat areas where vegetative cover is either absent or may have poor growth form indicative of stress-related phytotoxic conditions. However, these areas may serve as wildlife corridors between other less stressed habitats (EnviroSystems, 2009).

The general habitat types found at the Site are presented on Figure 5-14. Terrestrial habitats immediately surrounding the former Iron King Mine property and the former Humboldt Smelter property include areas of residential development (single-family homes), limited commercial development (predominantly along Highway 69 and in downtown Humboldt), interior chaparral and semi-desert grassland cut by unpaved roads, and riparian habitat (lower Chaparral Gulch and the Agua Fria River).

The former Iron King Mine property is located in the Arizona chaparral subtype of the Interior Chaparral Biotic Community, which is composed of chaparral, pinyon/juniper woodlands, and grasslands (EnviroSystems, 2009). Terrestrial habitats surrounding the former Iron King Mine property are dominated by shrub live oak (*Quercus turbinella*), along with oneseed juniper (*Juniperus monosperma*), alligator juniper (*Juniperus deppeana*), and Arizona walnut (*Juglans major*). Tree species observed on upland areas generally exhibited shrub form with few exceeding 15 feet in height. Shrub and half-shrub species and annual and perennial grasses and forbs are also present, particularly where the overstory canopy is open or only moderately dense. Due to the relatively high percentage of crown cover (50 to 60 percent) in many areas, grasses and forbs were not abundant except in interscrub openings and disturbed areas that are beginning to recover.

Vegetation on the former Humboldt Smelter property is also characterized as the Arizona chaparral subtype biotic community (EnviroSystems, 2009). However, relatively flat upland plant communities to the south of the former smelter facility and lying between the Agua Fria River and Chaparral Gulch exhibit characteristics of semi-desert grasslands. Large areas of the former Humboldt Smelter property exhibited conditions generally unsuitable for supporting vegetative cover (including areas shown as "disturbed/bare soil" on Figure 5-14). These areas include much of the Smelter Tailings Swale, portions of the Tailings Floodplain, dross areas within the former Pyrometallurgical Operations area, and slag adjacent to the Agua Fria River (see Figure 2-2 for the locations of these site features). It is likely that wildlife utilize these areas as habitat corridors. Slag piles that overhang the Agua Fria River may also serve as escape cover and roosting or nesting areas for birds.

In 2014, EPA performed a bench-scale plant growth study and agronomic analyses (Section 4.5.12) to investigate the reasons for the barren soil in the Tailings Floodplain (northwest of the Chaparral Gulch Dam) and dross areas at the former Humboldt Smelter property (Lockheed Martin SERAS, 2015). Testing was also performed for MTP tailings at the former Iron King Mine property. The testing analysis showed that plant growth was possible in the soil from the barren areas, but it was severely inhibited relative to plant growth in soil collected from the vegetated areas of the Tailings Floodplain. The pH of the barren areas of the Tailings Floodplain and samples from the MTP was low, and the Tailings Floodplain soils were classified as acid-producing soils. In addition, wicking to the soil surface in the barren areas has created salt precipitates. The electrical conductivity of all soils was high. The acidic conditions (Tailings Floodplain and MTP) and high electrical conductivity (Tailings Floodplain, MTP, and dross areas) appear to inhibit plant growth and germination in the barren soils. In addition, the metals concentrations are high and the nutrient content low; these conditions further inhibit plant growth.

As discussed previously, three natural waterways are found in the study area: (1) the Agua Fria River; (2) Chaparral Gulch; and (3) Galena Gulch. The Agua Fria River is perennial in the vicinity of the Site, and the two gulches are intermittent drainages. The edges of the Agua Fria contain abundant aquatic herbaceous vegetation (Lockheed Martin SERAS, 2015). The stream bottom consists of generally smaller stones, gravel, and coarse sands. Nearly all of the stream bottom was found to be covered with a very thick layer of green string algae. This string algae is indicative of excessive nutrient loading and eutrophication from farms or pasture, or runoff from residential irrigation upstream of the Site. The shallow borders of the stream are framed with an almost monoculture of nonnative water cress (*Nasturtium officinale*).

The riparian corridor along the Agua Fria has grasses established in open areas along with sedges and rushes (*Carex, Juncus*, and *Scirpus spp.*) along the stream (Lockheed Martin SERAS, 2015). Tree species found along the riparian corridor included abundant willows (*Salix gooddingii* and others), Freemont cottonwood (*Populus fremontii),* and nonnative tamarisks (*Tamarix sp.*).

Wetland conditions along the lower Chaparral Gulch were evaluated by WestLand Resources, Inc. (2009). Water flow in Chaparral Gulch is ephemeral from storm runoff events. However, seven wetland areas were identified along the lower portion of the gulch on the former Humboldt Smelter property (Figure 5-15). The largest wetland ("A") is located below the Chaparral Gulch Dam and is the result of a continuous seep of groundwater from the dam. Vegetation in this wetland is dominated by Goodding willow (*Salix gooddingii*), Freemont cottonwood, broadleaf cattail (*Typha latifolia*), American bulrush (*Schoenoplectus americanus*), softstem bulrush (*Schoenoplectus tabernaemontani*), and Mexican rush (*Juncus mexicanus*). Four smaller wetlands ("B", "C", "D", and "F") are primarily scrub-shrub with some emergent wetlands. Wetlands "E" and "G" (Figure 5-15) are adjacent to the relatively undisturbed southwestern slope of Chaparral Gulch. Based on historical photographs and sedimentation, it is believed that these wetland areas formed after 1970 (WestLand Resources, Inc., 2009).

Based on available documents in the site record, formal wetland delineations have not been conducted for other portions of the site.

5.6.2 Wildlife

Minimal animal life was observed during the biological evaluation (EnviroSystems, 2009) and reconnaissance-level biological survey (Lockheed Martin SERAS, 2015). Species that were observed included Common Rock Doves (*Columba livia*), Gambel's Quail (*Callipepla gambelii*), roadrunner (*Geococcyx californianus*), and mourning doves (*Zenaida macrooura).* Deer tracks were observed in some areas although no actual deer were noted. A couple of desert cottontails (*Sylvilagus auduboni*) were noted in the nonresidential upland areas. Small mammal burrows were extremely numerous over parts of the Site. These were readily apparent along the Agua Fria River and in areas west of the Tailings Floodplain. The inhabitants of the burrows were not observed and are most likely nocturnal. A few small lizards were observed but not frequently, probably due to the season and cool nights.

Fish were readily apparent in the Agua Fria River (Lockheed Martin SERAS, 2015). These appeared to be a small species of Dace (*Rhinichthys osculus*). Crayfish were abundant at all locations, some quite large. Tadpoles were also found at one of the sampling locations and appeared to be from a species of toad (*Bufo*), although no adult toads were observed. A male mud turtle (*Kinosternon arizonense*) was also observed in the shallow of the Agua Fria River. A fairly diverse benthic community was found during surveys conducted by Lockheed Martin SERAS (2015). Differences in the benthic community, species, or general abundance of organisms were not observed between sections of the Agua Fria River that were upstream and downstream of the Site.

5.6.3 Special-Status Species

Sixteen special-status species were identified as potentially occurring in Yavapai County, Arizona (EnviroSystems, 2009). Of these, suitable habitat is present in the study area for six species; however, none of the species have been recorded as being observed onsite during subsequent field events. Suitable habitat occurs in the Agua Fria River for the gila chub (*Gila intermedia*, federally listed as endangered), headwater chub (*Gila nigra*, federal candidate for listing), roundtail chub (*Gila robusta*, federal candidate for listing), Arizona toad (*Bufo microscaphus*, federal listing under review and an Arizona species of concern), and Chiricahua leopard frog (*Rana chiricahuensis*, federally listed as threatened and an Arizona species of concern). The Agua Fria River is also designated critical habitat for the northern Mexican garter snake (*Thamnophis eques megalops*, federally listed as threatened and an Arizona species of concern) (U.S. Fish and Wildlife Service IPaC, 2015).

5.7 Demographics and Land Use, Town of Dewey-Humboldt

This section provides a description of the demographics and land use/reuse in the vicinity of the Site.

5.7.1 Demographics

The following demographic information was obtained for the Town of Dewey-Humboldt from the 2010 Census (U.S. Census Bureau, 2010), 2009-2013 American Community Survey 5-Year Estimates (U.S. Census Bureau, 2013), and the Community Profile for Dewey-Humboldt (Arizona Commerce Authority, 2015). Demographic information can help identify potential human receptors during the RI, including vulnerable groups such as children, the elderly, and low-income and minority populations.

According to the 2010 Census, the total population of Dewey-Humboldt was 3,894. The total population estimated by the 2009-2013 American Community Survey was 3,914. Of that population:

- Approximately 21 percent of the population was over the age of 65, which is above the Arizona state average of 14.4 percent. Approximately 21 percent of the population was under the age of 19.
- Among the population over age 25, 89 percent were high school graduates and 13 percent had a Bachelor's degree or higher.
- There were 1,589 occupied housing units in the town and the average household size was 2.4 for owner-occupied units and 2.7 for renter-occupied units.
- Minorities accounted for a small percentage of the total population in the 2010 Census. Among the minority population, a total of 11 people identified themselves as Black or African-American; 40 as American Indian and Alaska Native; 8 as Asian; 408 as Hispanic or Latino; and 100 as two or more races.
- According to the American Community Survey data, the median family income in Dewey-Humboldt was $41,310, which was below the median family income in Arizona of $49,744. The poverty rate was 9.8 percent. The unemployment rate was 2.8 percent in 2000 and 4.0 percent in 2014 (Arizona Commerce Authority, 2015).
- Approximately 11.1 percent of the population was on disability status.

Education, health care, social assistance, construction, and retail establishments accounted for more than 50 percent of employment in the area in 2014. The Humboldt Unified School District is one of the largest employers in the area (Arizona Commerce Authority, 2015). The Humboldt Elementary School is located approximately 0.5 mile northwest of the former Humboldt Smelter property.

5.7.2 Land Use/Reuse

Current and reasonably anticipated future land uses were utilized in this RI Report to identify potentially exposed populations and determine exposure patterns to potentially contaminated media.

5.7.2.1 Current Land Use

Figure 5-16A shows regional land use zoning for the Town of Dewey-Humboldt and adjacent areas. Figure 5-16B shows detailed land use zoning in the vicinity of the Site.

Approximately 3,300 Assessor's Parcel Numbers (APNs) exist within the boundaries of the Town of Dewey-Humboldt. Approximately 71 percent of the town is developed in, or designated for, single-family residential land use, while 24 percent of the land is managed by public agencies, including Bureau of Land Management, Arizona State Trust Lands, and right-of-way easements (Town of Dewey-Humboldt, 2009). Less than 5 percent of the town is allocated to commercial and industrial uses. Commercial areas exist at the intersection of State Highways 69 and 169, along Highway 69 in the southern end of the town, and along Prescott and Main Streets within Humboldt Proper (just north of the former Humboldt Smelter property) (see Figure 5-16A).

Commercial land uses are granted by the town on a small scale for the convenience of residents and visitors (Town of Dewey-Humboldt, 2009). The former Iron King Mine property, the former Humboldt

Smelter property, and adjacent areas are currently the only industrial zoned properties in the vicinity (Figure 5-16B). Agricultural lands are located west of the Agua Fria River and east of Highway 69 between Humboldt and Dewey Proper (Figure 5-16A) (NRCS, 2007a).

The Town Council is committed to maintaining the rural flavor of the area (residential lots are typically greater than 0.5 acre with most areas 1.6 acres or greater) (Arizona Commerce Authority, 2015). The town offers abundant open spaces and outdoor recreational opportunities. The town is surrounded by public lands, including the Prescott National Forest to the west and east (Figure 5-5), as well Bureau of Land Management and Arizona state land (Figure 5-16A) (Greater Prescott Regional Economic Partnership, 2014). The town is currently partnering with Prescott National Forest to construct a multi-use trailhead to provide easy access to the Prescott National Forest trails; this trailhead is expected to be completed in 2016. Mortimer Family Farms is located near the intersection of State Highways 69 and 169 in the Dewey area and provides seasonal events (Arizona Commerce Authority, 2015).

5.7.2.2 Future Land Uses and Reuse Assessment

CERCLA remedy selection determines the extent to which hazardous constituents remain at the Site, and therefore impacts subsequent available land and groundwater uses. Future land use assumptions allow the cleanup alternatives evaluation to be focused on developing practicable and cost-effective remedial alternatives. Possible future land uses following completion of site cleanup are taken into account during the remedy selection process. This section briefly discusses possible future land uses, as presented in the Town of Dewey-Humboldt General Plan (2009) and the EPA reuse assessment (E2 Inc., 2010). More detailed evaluation of possible future land uses and stakeholder considerations could performed in the FS.

The Town of Dewey-Humboldt General Plan is a guide to the future of Dewey-Humboldt and serves as a framework for revising the community’s planning directions (Town of Dewey-Humboldt, 2009). The town’s vision for the future focuses on preserving its low-density lifestyle and rural character. According to the General Plan, future development may include limited commercial expansion as needed to fit the needs of the community, but industrial uses would likely not be consistent with the future vision. The town’s future land use plan designates the former Iron King Mine and Humboldt Smelter properties as a special study area. While the underlying zoning remains industrial, the town’s goal is that the future land use of these areas will be consistent with the General Plan and Vision. The Town may reevaluate the special study area designation as more information about the Site becomes available or after the EPA completes the RI/FS for the Site. As an example, the General Plan includes the former Humboldt Smelter property in an area of proposed “Open Space/Recreation,” with proposed trails accessing the northeastern portion of the property.

As a part of the Initial RI phase, EPA’s Abandoned Mine Lands Team worked with the community, site owners, and other stakeholders to perform a reuse assessment (E2 Inc., 2010; see Section 4.2.7.6). On July 21 and 22, 2009, EPA and E2 Inc., performed initial interviews with community stakeholders to gather a preliminary set of reuse goals and considerations. Stakeholders included current site owners, elected officials, ADEQ, representatives for the Town of Dewey-Humboldt, and interested community members at the July 22, 2009, town council meeting. Stakeholders identified the following reuse goals for the Site (E2 Inc., 2010):

- Encourage future uses that are consistent with the town’s General Plan (Town of Dewey-Humboldt, 2009) (preserve low-density lifestyle).
- Ensure continued industrial uses are contained and regulated by ADEQ.
- Provide public educational resource on former mining and smelter activities.
- Foster renewable energy opportunities.

- Provide public recreational access.
- Ensure individual economic development opportunities.

E2 Inc. performed subsequent interviews, reviewed pertinent documents such as the Town of Dewey-Humboldt's General Plan (2009), performed a site visit, and characterized the site, including ownership, zoning and surrounding land uses, access, utilities, topography, physical features, areas of contamination, and views. This information was used to identify the following future use opportunities for the former Iron King Mine property and former Humboldt Smelter property:

- Continued manufacturing/light industrial use
- Mining or heritage museum
- Recreational access to surrounding trails and open space
- Siting renewable energy projects

Data gathered during the reuse assessment will be used in the identification and evaluation of remedial alternatives in the upcoming FS.

SECTION 6

Data Evaluation Methodology

This section describes the data evaluation methods used to assess the nature, extent, fate, and transport of contamination and to prepare the baseline risk assessments for the Iron King Mine – Humboldt Smelter Superfund Site. For this RI Report, the methodology was designed to accomplish the following:

- Compile, review, and evaluate the data collected as part of the preliminary investigations, removal actions, and RIs (described in Sections 3 and 4).
- Meet the investigation objectives including assessment of the nature, extent, fate, and transport of site-related contaminants (Sections 7 and 8).
- Prepare the baseline risk assessments for the Site (Sections 9 and 10).

The process consisted of the following steps:

1. Review of available data to determine its usability for evaluating the nature and extent of contaminants and for assessing risk (Section 6.1).
2. Estimation of background concentrations for surface soil and identification of the APSI (Section 6.2).
3. Identification of media-specific screening levels that can be used to identify COIs and delineate the nature and extent of contamination (Section 6.3).
4. Comparison of analytical results to background concentrations and media-specific screening levels to identify preliminary COIs. Preliminary COIs are chemicals with concentrations that exceed screening levels in at least one sample and exceed background concentrations, where developed (Section 6.4).
5. Identification of primary COIs for analyte groups and media based on the number of screening level exceedances, the magnitude of screening level exceedances, and the distribution of concentrations relative to Site source areas (Section 6.4).
6. Site-specific analysis of geochemical signatures including (a) key metals concentrations for lead, copper, and zinc; and (b) the ratio of lead to copper and zinc to copper concentrations, to assist with the evaluation of the origin, fate, and transport of contaminants (Section 6.5).
7. Grouping of sample results into “exposure areas” based on geographic areas, media, and potential exposures (Section 6.6).
8. Evaluation of the distribution of the representative COIs for each analyte group and media, and calculation of the volume of source materials (Section 7).

As discussed in Section 3, soil removal actions were performed at selected residential and municipal properties in 2006 and 2007 by Brown and Caldwell on behalf of Ironite Products Company (Brown and Caldwell, 2007) and in 2011 by EPA (E & E, 2012). To allow a comprehensive evaluation of the current and historical nature, extent, and contaminant transport pathways, pre-removal concentrations are used in the nature and extent evaluation (Section 7) and the fate and transport evaluation (Section 8). Because the removed media no longer contributes to risks associated with the Site, however, pre-removal concentrations are excluded from the risk assessments (Sections 9 and 10).

The following sections describe the data methodology steps in more detail.

6.1 Data Usability and Processing

This section provides a description of the data management activities associated with compiling data from multiple investigations, correlation of portable XRF spectroscopy data with laboratory analyses, and the data reduction procedures.

This section addresses data usability and processing for the risk assessments, in addition to defining nature and extent, to provide an understanding of the differences in data reduction for each purpose. However, Sections 9 and 10 provide more detail regarding the data review and evaluation processes used for the human health and ecological risk assessments, respectively.

6.1.1 Data Compilation and Management

CH2M used imported data from EPA's previous contractor (EA) and ERT for this RI as follows:

- ERT imported data from the 2013 to 2015 Data Gap RI, including field measurements, geospatial data (GPS data), sampling data, and analytical results, into a Scribe database (provided as Appendix A of the ERT report [Lockheed Martin SERAS, 2015]). Scribe is a software tool developed by the EPA ERT to assist in the process of managing environmental data, which is stored in a Microsoft Access database. Data in the Scribe database may be utilized directly through Scribe or through database management software such as Microsoft Access.
- EPA contractor EA maintained a Microsoft Access RI database that included data from 2002 through the Initial and Supplemental RIs.

CH2M and CH2M's subcontractor Critigen consolidated data from the EA and ERT databases into a relational, comprehensive, Microsoft Access Site database. As part of this process, CH2M and Critigen standardized fields, added data that were identified as missing, performed data reduction procedures (discussed below), and performed other improvements to provide increased data quality and ease of access to users.

Data from the following pre-NPL and RI investigations (described in Sections 3 and 4) are included in the Site database (see Appendix G):

- 2002 PA/SI of the Former Iron King Mine Property (ADEQ, 2002)
- 2004 PA/SI of the Former Humboldt Smelter Property (ADEQ, 2004)
- 2005 EPA Removal Assessment (E & E, 2005)
- 2006 ESI (ADEQ, 2006)
- 2008 Ironite Products Company/North American Industries Sampling (Brown and Caldwell, 2009b)
- 2008 to 2009 Initial RI (EA, 2010)
- 2010 and 2012 Supplemental RI (EA, 2011)
- 2012 to 2013 Background and Surface Soil Sampling (EPA, 2012b)
- 2013 to 2015 Data Gap RI (Lockheed Martin SERAS, 2015)

This RI Report evaluates analytical data for the following media sampled during the pre-NPL and RI investigations, including:

- Soil
- Sediment
- Surface water
- Groundwater
- Ambient air

Samples of source material collected during the various investigations included waste rock, tailings, slag, and dross. The medium assigned to these source materials was standardized by EA or ERT as "soil" or "sediment" in the Site database, depending on the location relative to surface water features and degree of saturation. It should be noted that the sample location designations were identified during each investigation, and are not necessarily indicative of a source material type. For example, samples labeled "ASH-" were collected in 2014 as part of the data gap dross investigation (Lockheed Martin SERAS, 2015); all have a "Soil" matrix in the Site database, but are classified in the ERT report as both dross or non-dross materials.

In this RI, in specific instances where it was feasible and deemed necessary to understand the nature and extent or fate and transport of contamination, soil and sediment samples were further delineated by source material using a combination of boring logs and EA or ERT report descriptions.

Analytical data are available for one or more of these media for the following groups of chemicals:

- Metals
- VOCs
- SVOCs, including PAHs
- PCBs
- Pesticides
- Dioxins and furans
- Explosives or perchlorate
- Major anions and cations
- Nitrogen compounds
- General chemistry

The Site database contains over 200,000 analytical data records, in addition to the field and lithologic datasets, collected over 12 years (from 2002 to 2014).

6.1.2 X-ray Fluorescence Data Correlations

Beginning with the 2008 to 2009 Initial RI (EA, 2010), sampling teams used portable XRF for analysis of metals in soil to streamline data collection and reduce laboratory analytical costs. Use of the XRF data allows for substantially greater geographic coverage and density of the analytical results than use of laboratory analytical data alone.

In each investigation, sampling protocols for XRF analysis included the periodic collection of paired samples for laboratory analysis. To account for inherent differences between the XRF and laboratory analysis, and to generate a consistent dataset between the two methods, regression analyses were used in this RI to compare paired XRF and laboratory data and to develop correlation equations for each metal/metalloid. Correlation equations were then used to adjust the field XRF data to better correspond to the laboratory analytical data, and the adjusted XRF data were subsequently incorporated into the Site database. The database for this RI Report uses the adjusted XRF data when laboratory results are not available. Both metals and metalloids are referred to as "metals" for ease of reference in this RI.

To account for slight differences in field XRF methodology between the various investigations, separate correlation equations were developed in this RI for each investigation (the 2008 to 2009 Initial RI [Section 4.2], the 2012 to 2013 Background and Surface Soil Sampling [Section 4.4], and the 2013 to 2015 Data Gap RI [Section 4.5], which included residential sampling performed in 2013 [Section 4.5.13]). For a detailed description of the regression analysis process, refer to the *Soil Background Study Report* (CH2M, 2015; included as Appendix E of this RI Report).

The 2013 to 2015 ERT Data Gap RI (Lockheed Martin SERAS, 2015), included as Appendix F of this RI Report, is referred to throughout the nature and extent evaluation (Section 7) and the fate and transport evaluation (Section 8). The ERT report presents raw, unadjusted XRF data, however, which will differ from the adjusted XRF data used in this RI Report. Therefore, although conclusions and data trends discussed in the ERT report are applicable, the individual datasets differ between the ERT report and this RI Report.

6.1.3 Data Reduction Procedures

CH2M performed data reduction procedures that were specific to the intended use in this RI Report. This section first discusses the reduction procedures performed for all RI datasets, and then discusses data reduction procedures for the following specific datasets:

- Nature and extent evaluation
- Ratio calculations for evaluating the origin of contaminants as well as fate and transport of contaminants
- Risk assessment

6.1.3.1 Procedures Applied to All Remedial Investigation Data

Laboratory analytical data were assigned validation flags during the pre-NPL and RI investigations. As an example, for the Initial and Supplemental RIs (EA, 2010, 2012), the EPA Region 9 Laboratory and CLP laboratory completed an in-house review and validation of laboratory analytical results. Details regarding data validation and management performed as part of the 2013 to 2015 ERT Data Gap RI are presented in Section 13 of the ERT report (Lockheed Martin SERAS, 2015).

The data validation flags were reviewed as part of this RI to confirm the usability of the data. The following are key data validation flags that were considered in the data reduction process:

- Estimated values (flagged with “J” qualifiers) were treated as detected concentrations.
- Rejected data (flagged with “R” qualifiers) were not used in this RI because of deficiencies in meeting quality control criteria.
- Results with final validation qualifiers containing a “U” or “UJ” were considered not detected.

In addition to R-flagged data discussed above, the following additional data were excluded from the RI datasets:

- Soil data without sample coordinates and that could not be associated with a specific sampled area were excluded.
- Analytes that were detected but no result was provided, or analytes that were not detected and the reporting and method detection limits were unknown, were excluded.
- Historical analytical data that were not readily available (for example, were only included in hard copy reports), and for areas in which more recent and more extensive data were available were excluded. An example is the 2002 surface water data collected during the PA/SI of the former Iron King Mine property (ADEQ, 2002). The electronic dataset in the EA database was incomplete, and numerous surface water data have been collected at the sample locations in 2008 and 2009 as part of the Initial RI (EA, 2010) and in 2014 as part of the Data Gap RI (Lockheed Martin SERAS, 2015). While all available data are included in the Site database, the data collected from post-NPL investigations in 2008 through 2015 provide the necessary data for this RI.
- The Initial RI surface water samples collected between August 24 and 26, 2008, and ending with “B” in the sample ID were excluded. In all cases, a sample ID ending in ”B“ was assigned to one of two samples for the same location, date, and sample fraction. Results for the ”B“ sample were anomalously high relative to the other sample. These data are not documented in the Initial RI (EA, 2010), and there is no explanation provided as to the sample collection methods. For these

reasons, the "B" samples were excluded, and results from the original samples (without the "B") were used in this RI Report.

For remaining data, stored structured query language (SQL) procedures were used to select the "Best Result" for each unique combination of sample media, location ID, sample date, sample depth, analyte, extraction (for example, extraction entries included SPLP and total for soil), and fraction (for example, total and dissolved for water analysis). These procedures conservatively select one result for native/field duplicate pairs, analytes detected using field (XRF spectroscopy) or certified laboratory analytical procedures, or analytes reported under multiple laboratory methods. The Best Result decision rules are as follows:

- If a specific sample contained both certified laboratory analysis and field analysis by portable XRF spectroscopy, the laboratory analytical data were used.
- If there were multiple detections, the highest concentration was used.
- If there was only one detection and the other results were nondetections, the detected value was used.
- If there were only nondetections, the result associated with the lowest detection limit was used.
- For laboratory or field pH measurements, the minimum value was selected as the Best Result. This is a conservative approach for this Site, in order to monitor the potential generation of acidic conditions due to site-related impacts such as acid rock drainage (ARD) (see Section 8).

The Site database has been populated with fields to indicate the "Best Result" for the RI dataset according to the rules above, as well as fields that differentiate the "Usable Best Result" for each of the individual datasets using additional criteria discussed below.

Samples classified as a medium of "Soil" were further subdivided into the following categories for data analysis and evaluation:

- Surface soil: Samples with a beginning depth less than or equal to 2 feet bgs
- Subsurface soil: Samples with a beginning depth greater than 2 feet bgs

An areal average surface soil concentration (as represented by the 95 percent upper confidence limit [UCL] of the mean) was calculated for individual exposure areas (see Section 6.6). This concentration is referred to as the exposure point concentration (EPC) and was primarily used to assess human health risks (see Section 9), but also was used to evaluate the nature and extent of arsenic and lead contamination on an area-specific basis. EPCs were generated from the maximum concentration detected for samples flagged as "Best Result" from the 0 to 2-foot depth range.

6.1.3.2 Use of Removal Action Data

As discussed in Section 3, soil removal actions were performed at selected residential and municipal properties in 2006 and 2007 by Brown and Caldwell on behalf of Ironite Products Company (Brown and Caldwell, 2007) and in 2011 by EPA (E & E, 2012). To allow a comprehensive evaluation of current and historical nature, extent, and contaminant transport pathways, pre-removal concentrations are included in figures and tables used to support the nature and extent evaluation (Section 7) and the fate and transport evaluation (Section 8). Because the removed media no longer contributes to risks associated with the Site, however, pre-removal concentrations are excluded from the risk assessments (Sections 9 and 10).

6.1.3.3 Use of Ratio Calculations in the Nature and Extent Evaluation and the Fate and Transport Evaluation

The nature and extent evaluation and the fate and transport evaluation included the use of concentration ratios calculated to illustrate the origin of site-related contaminants and the extent of migration. The ratio of shallow to deep sample concentrations was calculated as part of the development of the background boundary and APSI as an indication of the extent of mine- and smelter-related impacts (see Section 6.2). The ratio of lead to copper and zinc to copper concentrations was calculated as one method of differentiating Iron King Mine and Humboldt Smelter tailings (see Section 6.5). The ratio data were further filtered from the nature and extent dataset in order to pair the data appropriately.

The following additional data reduction rules were applied for the ratio calculations used in preparing the figures for the nature and extent evaluation (Section 7, Figures 7-5 through 7-10) and the fate and transport evaluation (Section 8, Figures 8-5 and 8-6). Ratios were not calculated for samples where one of the concentrations was a nondetect.

- Ratios were calculated to compare results from samples with a quality assurance/quality control classification of normal, rather than selecting the Best Result of the normal and field duplicate samples.
- Soil sample media were further refined for the ratio calculations as follows:
  - "Shallow" samples used in the ratio calculations were defined as samples with a beginning depth of 0 feet bgs.
  - "Deep" samples used in the ratio calculations were defined as samples with a beginning depth greater than 0 feet bgs.

Additional details on the data reduction procedures and calculations used in generating the background boundary and lead to copper and zinc to copper ratios are presented in Appendixes E and I, respectively.

6.1.3.4 Procedures Applied to Data used for Risk Assessment

The data quality requirements for risk assessment are more stringent than those for evaluating the nature and extent of contamination. The risk assessments will be used to make informed risk management decisions in the decision documents for this Site, based on current Site conditions. The data reduction procedures for the risk assessments are summarized here in Section 6, and discussed in more detail in Sections 9 and 10.

The risk assessments used analytical data collected from the following environmental media (see Sections 9 and 10 for rationale).

- Surface soil (from 0 to 2 feet bgs)
- Ambient air (HHRA)
- Agua Fria River sediment (from 0 to 0.5 foot bgs); as discussed further below, the Agua Fria River is the primary surface water feature in the valley and is considered the only true aquatic habitat in the APSI
- Agua Fria River surface water

The risk assessment dataset excluded the following additional data, in comparison to the nature and extent dataset:

- Pre-removal samples: The risk assessment excluded samples collected prior to removal actions in residential yards subject to "complete" removal (all or a majority of the yard was remediated), or in the area of the former Small Tailings Pile (see Section 3). The risk assessment also excluded samples collected from a residential yard subject to "partial" removal action (the removal action was completed, but consisted of removing only a portion of the yard as deemed necessary), if the specified sample was located within the removal area. These samples no longer represent current conditions.

- Samples without location coordinates: The risk assessments excluded samples where location coordinates were not available, unless the sample could be linked to a specific residential yard or specific risk assessment area.
- XRF chromium and copper data: Copper and chromium were analyzed by XRF methods as part of the ERT data gap investigation. In contrast to correlation coefficients for arsenic, iron, lead, manganese, and zinc, which were close to or greater than 0.9, the correlation coefficients for chromium and copper were less than 0.5 and 0.3, respectively, indicating a lack of a strong association between the XRF and laboratory values. For this reason, and because chromium and copper are not risk drivers, the risk assessment only used copper and chromium Best Results derived from laboratory analytical methods. XRF chromium and copper data were omitted from the risk assessments. The nature and extent dataset used the chromium and copper XRF data to allow for greater geographic coverage and density of the analytical results.
- Samples outside of exposure areas: EPCs were not calculated for samples not captured within an exposure area (defined in Section 6.6) (for example, samples along roadways or areas far south of the Site).
- Air samples collected using continuous particulate monitors: As part of the Initial RI (EA, 2010) (see Section 4), ambient air samples were collected using BGI PQ100 samplers and continuous particulate monitors, the Thermo Electron TEOM Series 1400a (TEOM) samplers. The TEOM samplers were intended to characterize high wind events, and were biased to only include sampling when specified TSP thresholds were exceeded. As a result, they include only episodic events that are not considered representative of the chronic exposure conditions that are assumed for the HHRA.

The data reduction procedures described above were used to generate a robust dataset that is of suitable quality for assessing risk, and is considered adequate for reliable risk management decisions for the Site.

6.2 Background and Area of Potential Site Impact

The soil background study (CH2M, 2015) performed as part of this RI (and included as Appendix E) focused on using site-related indicator parameters (copper and zinc) and ratios of shallow to deep metals concentrations to differentiate between site-affected areas and background areas. This approach allowed the calculation of defensible background concentrations for arsenic, lead, copper, and zinc, and established an approximate geographic extent of potential site-related impacts, referred to as the APSI, that bounded the extent of investigation during the ERT data gap investigation. The APSI was determined by a rigorous and statistically based analysis of metals concentrations in soils spatially distributed up to 3 miles distant from the former mine and smelter operations. The APSI was based on several independent lines of evidence; its derivation is described in detail in Appendix E. In 2015, after completion of the soil background study, CH2M developed background concentrations for an expanded list of metals and metalloids, primarily in support of the risk assessments, but also for use in the nature and extent evaluation.

The objectives and rationale for the soil background study are presented below, following by a detailed discussion of the individual steps taken in developing background concentrations and the APSI.

6.2.1 Rationale

The distribution of metals in soil in areas surrounding the former Iron King Mine and former Humboldt Smelter properties is influenced by a number of factors, including the following:

- Mine and smelter operations
- Historical smelter stack emissions and aerial dispersion of tailings, dross, or fine-grained particulates

- Geologic conditions, which are highly variable and result in varying metals concentrations in area soil
- Anthropogenic factors, such as using mine waste (or using material from other quarries with naturally elevated concentrations) as construction fill, road base, or landscaping material
- Use of fertilizers or pesticides that contain arsenic

Arsenic and lead are the most prevalent contaminants in soil at the Iron King Mine and Humboldt Smelter sites. However, these constituents are also encountered at naturally elevated concentrations in the surrounding regions. The geology results in varying levels of metals, and arsenic concentrations in particular, in rock and soils. Arsenic is elevated at the Iron King Mine site due to the presence of arsenic-bearing sulfide minerals in the Iron King Mine deposits. However, the Iron King Mine is not the only mineral deposit in the region with arsenic-bearing minerals. Naturally occurring arsenic is common for gold-bearing veins and is also associated with silicic volcanic materials such as rhyolite, which are widely present within the region. Lead is also elevated at the Iron King Mine site as a result of the mineral deposit. However, other sources of lead, especially in the residential areas, could include lead-based paint, soldering operations, and historical use of leaded gasoline, in addition to other unknown sources of lead.

In addition to naturally occurring or non-site-related sources, multiple release and transport mechanisms from the Site have contributed to the current distribution of contamination. Dispersive/depositional influences could include either historical emissions from the smelter stack or tailings and dross piles during operations; or more recent emissions from the residual piles due to wind. The chemical content of each of these mechanisms may be different. The distance to which smelter stack emissions may have traveled, as well as their metals content, could have been influenced by particle size. Due to the significant period of time since the operation, such information is not readily obtainable.

In addition, human activity in the area, including industry, construction, soil cut-and-fill, and landscaping, has modified the historical distribution of contaminants. Fill material, possibly from quarries some distance from the sites, as well as waste rock or tailings themselves, may have been brought into yards by landowners or developers as fill or landscaping material. Arsenic-containing (tailings-based) fertilizers were also used residentially in the valley at times in the past (EPA, 2012b).

Discerning trends and correlations can be difficult at many locations due to overlapping modes of influence discussed above. The distribution of arsenic and lead cannot always be attributed to operations related to the Iron King Mine and Humboldt Smelter, and cannot serve as a sole basis for remedial decisions for the Site. Evaluating a background level and spatial area of influence for the sources was required and involved use of a multiple line of evidence approach.

The soil background study focused on identifying indicator parameters that could be used to differentiate between the areas affected by the Iron King Mine- and Humboldt Smelter-related contaminants and background areas (that have not been impacted by the Iron King Mine and Humboldt Smelter operations) and defining the APSI. The primary steps of the technical approach used for the soil background study included the following:

1. Identifying site indicator parameters based on the evaluation of available soil data, assessment of the local geologic conditions, and assessment of the potential distribution patterns of chemical constituents associated with the site operations.
2. Identifying the background boundary using multiple lines of evidence developed based on site-specific characteristics, local and regional geology, distribution of soil concentrations, and other factors.

3. Estimating background values of indicator parameters and COIs based on the available soil samples collected in the background area.
4. Identifying the APSI based on the estimated background values of the indicator parameters and comparison of these values with available soil concentration data.

Each of these steps is discussed in detail below.

6.2.2 Indicator Parameters

Regional geologic conditions were evaluated as part of the soil background study to assess natural sources of metals encountered at the Site, and determine whether some of these metals are uniquely characteristic of the Iron King Mine and Humboldt Smelter conditions. Indicator parameters for the site-affected areas were identified by evaluating distribution patterns for all metals detected in available soil samples, with an emphasis on metals identified during the assessment of geologic conditions.

As discussed in the *Soil Background Study Report* (CH2M, 2015), zinc was identified as the primary indicator parameter for the Iron King Mine-affected areas, because the Iron King Mine is the only base metal massive sulfide deposit in the region, and consequently is expected to have significantly higher concentrations of base metals such as zinc in comparison to the rest of the region. Copper was identified as the primary indicator parameter for the Humboldt Smelter-affected areas, because Humboldt Smelter was primarily a copper smelter. Both zinc and copper demonstrated a clear and consistent statistical difference in soil concentrations collected at and near the former Iron King Mine and Humboldt Smelter properties and regional concentrations, with a significant drop in concentrations with the distance from the mine and smelter properties (refer to Appendix E, Figures 3-3 and 3-4). This drop in concentrations of both metals with distance from the former Iron King Mine and Humboldt Smelter properties supports the conclusion of the geologic analysis that there is a limited occurrence of both metals in the regional geology outside immediate proximity to the mine and smelter properties.

Other base metals such as cadmium and lead also demonstrated a similar distribution pattern of abrupt concentration decrease with distance from the mine and smelter, but the pattern displayed by zinc and copper was more pronounced. The distribution of cadmium was similar to that of zinc, but cadmium was much less abundant in sulfide deposits, and its concentrations dropped below detection limits with distance from the mine. Lead has other potential anthropogenic sources in addition to the mine- and smelter-related operations, as discussed above (for example, lead-based paint and leaded gasoline); therefore, its distribution was less consistent than that of zinc and copper. Arsenic and aluminum distributions did not exhibit a clear pattern of concentration drop with distance from the mine and smelter. As discussed above, arsenic is present at high concentrations in both the Iron King Mine massive sulfide deposits and in fissure quartz vein deposits, as well as other materials present in the region. Similar to arsenic, the distribution of aluminum is impacted by enriched concentrations of this metal in volcanic rocks encountered within the region.

6.2.3 Background Boundary

The observed rapid decrease in concentrations of the indicator metals with distance from the mine and the smelter served as an initial line of evidence that a clear separation exists between naturally occurring soil constituents and those resulting from the mine and smelter operations. This section discusses an additional line of evidence, evaluation of the ratio of shallow to deep soil concentrations, used to delineate the natural unaffected soils that could be considered background.

The conceptual model for the background evaluation approach is that soils in the vicinity of the mine and smelter were potentially impacted by a combination of wind-blown dust and stack emissions, along with some fill and roadbed application of mine and smelter soil and/or waste rock/tailings. Based on these potential transport mechanisms for the Iron King Mine- and Humboldt Smelter-related contaminants, the surface and near-surface soils are likely more impacted by the mine and the smelter than deeper soils. Consequently, the concentrations of mine- and smelter-related contaminants are expected to be higher in surficial soils than in deeper soils in the areas impacted by the mine and smelter operations. By contrast, natural soils that have not been impacted by the Site are not expected to have shallow soil concentrations of chemical constituents that are significantly elevated compared to deeper soils. Based on the above, it is expected that a ratio of shallow to deep soil concentrations would be higher for the mine- and smelter-affected soils than for natural soils, in which shallow and deep concentrations are expected to be more comparable.

For this analysis, shallow samples were defined as samples with a beginning depth of 0 feet bgs, while deep samples were defined as samples with a beginning depth greater than 0 feet bgs. The shallow to deep ratio distribution plots for the indicator metals (zinc and copper), and COIs (arsenic and lead) indicated that ratios of shallow to deep concentrations above 2.5 for these metals are largely limited to the areas at and near the former mine and smelter. The shallow to deep ratio values for samples collected at a distance from the Iron King Mine and Humboldt Smelter Sites were consistently lower, and mostly below the value of 2.5. Based on these ratio distribution plots, a ratio of 2.5 appeared to be a reasonable threshold value for demarcating the naturally occurring soil representing background for the study area (that is, soils in which ratio values are mostly above 2.5 are considered to be potentially impacted by the mine and the smelter; and soils in which ratio values are mostly below 2.5 are considered to represent background).

An oval shape (Appendix E, Figures 4-1 through 4-4) delineates a frequency of occurrence for the threshold shallow to deep concentration ratio of 2.5 for each of the metals. The ratio distribution patterns are relatively similar for all metals considered, and resulted in the same consistent oval shape that demarcates the boundary between the potentially impacted and naturally occurring (background) soils. This consistency in the ratio distribution for all four metals indicates that the shallow to deep concentration ratio of 2.5 is a distinct site-specific characteristic that can be used at this Site for distinguishing background soils from potentially impacted soils. Based on this analysis, the soils in the area outside the oval shape are interpreted to represent the background; and soils inside the oval shape may potentially be impacted by the mine and smelter. The oval shape separating the potentially impacted soils from soils representing background is referred to as the “background boundary” and is shown on Figure 6-1.

It should be noted, however, that while this ratio analysis was deemed sufficient for separating the background soils from the potentially impacted soils (that is, it allows identification of the background dataset), it cannot serve as a sole basis for defining the areas impacted by the mine- and smelter-related sources. For example, in some locations, the mixing depth of surface soils may extend below the depth sampled, metals carried by rain infiltration may impact deeper soils, or human activity influences may be present where none is observed or expected. For these reasons, a multiple line of evidence approach was required in defining the APSI, including evaluating concentrations of indicator metals, as discussed further in Section 6.2.5.

6.2.4 Background Concentrations

6.2.4.1 Arsenic, Lead, Copper, and Zinc

Background concentrations for the primary COIs (arsenic and lead) and indicator metals (zinc and copper) were estimated using the statistical analysis of sampling data in the background area (area outside the background boundary) as part of the soil background study (CH2M, 2015). Prior to statistical analysis, the background dataset was evaluated with regard to (1) spatial differences in samples collected west and east of the Agua Fria River, (2) differences in samples collected at shallow and deeper depths in undisturbed locations, and (3) an outlier analysis to remove anomalous data.

The background datasets from the areas east and west of the Agua Fria River were evaluated to assess the potential differences in background concentrations due to the variability in rock types and distribution. East of the Agua Fria River, rhyolitic tuffs are common in the Spud Mountain, Indian Hills, and Texas Gulch Formations (see Figure 5-9 and Figure 3-2 in Appendix E). These rocks tend to have higher concentrations of arsenic than the other mixed volcanic and sedimentary rocks in the area. However, the former Iron King Mine and Humboldt Smelter properties and the adjacent areas, including Humboldt Proper, are situated at the convergence of drainages flowing from both the eastern and western parts of the region. These drainages have likely both contributed to the composition of soils in these areas. Therefore, the contribution of metals from the background areas is likely represented by a mixture of higher-arsenic-concentration soils derived from alluvial washout from the eastern part of the region and a lower-concentration washout from the western part of the region. In addition, these drainages, including the Agua Fria River, have altered their courses over recent geologic time, which further complicates the variable mixing pattern impacting the soils near the mine and smelter and in the town area. This complex mixing pattern of alluvial washouts from areas with a high variability of arsenic sources makes it impossible to differentiate between the impacts of background sources from the areas east and west of the Agua Fria River. Consequently, the final representative background values were estimated based on the combined dataset of samples collected in the areas east and west of the Agua Fria River.

Deep and shallow samples from the background dataset were also evaluated to assess if one, or a combination, of these datasets is more appropriate for estimating representative background values. While three sets of soil samples (shallow, deep, and a combination of both) were initially considered, the shallow sample dataset was ultimately selected for calculating the final representative background values for the following reasons:

1. There are more samples in a shallow dataset than in a deep dataset, which makes it more statistically representative.
2. The natural variability of metals, such as arsenic, is higher in the shallow dataset than in the deep dataset; capturing this variability is important for estimation of the representative background values.
3. Human receptors are more likely to be exposed to chemicals of concern (COCs) in the surficial soils than in deeper soils; consequently, understanding background concentrations of COCs in surficial soils is more important.

Finally, samples identified as part of the outlier analysis, which contained anomalously elevated concentrations of arsenic and copper, were removed from the background dataset for reasons such as: their locations were near the fault contact with quartz veins.

The results of statistical analysis are presented in Table 6-1, and include summary statistics and the 95th upper tolerance limits (95/95 UTL) for the indicator parameters, zinc and copper, and site COIs, arsenic and lead. The 95/95 UTLs are typically used in background investigations as bounding values designed to be greater than 95 percent of the values in the background population with a confidence of 95 percent. This is a conservative approach for defining background concentrations, because it allows up to 5 percent of soil samples with concentrations of target metals equivalent to the upper tail of background values to exceed the UTL and be considered “above background.”

The 95/95 UTL values and summary statistics were calculated using the Best Result from shallow soil samples (sample beginning depth of 0 feet bgs), collected between 2002 and 2013, from areas outside of the background boundary, both west and east of the Agua Fria River. The statistical software ProUCL was used to establish the data distribution for each parameter (that is, parametric [lognormal, gamma] or nonparametric; see Table 6-1) for calculation of the 95/95 UTL.

The 95/95 UTLs, which were used to define background for this RI, are 112 mg/kg for arsenic, 182 mg/kg for copper, 34.8 mg/kg for lead, and 136 mg/kg for zinc. These estimates indicate that the UTL for arsenic is significantly higher than that for lead. This is expected based on the regional geologic conditions, because arsenic is commonly found in the volcanic rocks of the region, while lead is scarce outside the massive sulfides of the former Iron King Mine area.

6.2.4.2 Other Metals

After completion of the soil background study, CH2M developed background concentrations for an expanded list of metals and metalloids, primarily to aid in the calculation of incremental site risks as part of the risk assessment, but also for use in the nature and extent evaluation. Cancer and noncancer risks from exposure to naturally occurring levels of metals and metalloids are estimated and reported in the risk assessments. Incremental risk is then calculated as the portion of the site risk in excess of that resulting from normal regional background/ambient concentrations of metals, and presumably attributable to site-related releases.

CH2M completed the additional background calculations in November 2015; the background summary statistics are presented in Table 6-1. The methods used to calculate the background statistics were consistent with methods described in the soil background study (CH2M, 2015; see Appendix E). The same sample dataset was used to calculate summary statistics for the additional metals as was used for arsenic, lead, copper, and zinc in the soil background study. The dataset includes the Best Result from shallow soil samples, defined as a top depth of 0 feet bgs, collected between 2002 and 2013, from areas outside of the background boundary, both west and east of the Agua Fria River. The total number of analyses is lower (approximately 160 compared with approximately 270), because not all samples were analyzed for the full suite of metals. The statistical software ProUCL was used to establish the data distribution for each parameter, and an outlier analysis was performed to identify samples that should be excluded from these background calculations. As discussed for arsenic, lead, copper, and zinc, the 95/95 UTL was selected as the representative background summary statistic for use in this RI Report.

6.2.5 Area of Potential Site Impact

The estimated background UTLs for the indicator parameters, copper and zinc, were used as a statistical basis for identifying the APSI. As discussed above, soils in the area outside the background boundary are designated as background, and soils inside the background boundary could potentially be impacted by the Iron King Mine- and Humboldt Smelter-related sources. To define the APSI, soils located inside the background boundary (soils that have not been considered background) were further evaluated to determine the extent of potential mine- and smelter-related impacts. For this evaluation, indicator metal concentrations (zinc and copper concentrations) in soil samples collected inside the background boundary were compared to the estimated background values of these metals (the 95/95 UTLs of zinc and copper). Soils with concentrations of zinc and copper exceeding the respective UTLs were considered to be likely impacted by the former mine and/or smelter operations, because zinc and copper serve as strong indicators for these impacts. Soils that have concentrations of zinc and copper below the respective UTLs were considered unlikely to be impacted by the former mine and smelter operations. The extent of the APSI was defined based on the frequency of shallow sample locations with concentrations of either zinc or copper exceeding the respective UTLs.

Figure 6-1 shows the background boundary as well as the boundary of the area identified as the APSI. Although concentrations of zinc and copper vary within the APSI, most soil samples near the boundary of this area exceed the UTLs for zinc and copper. Therefore, the APSI defines the general lateral extent of soils potentially impacted by the former mine and smelter operations. As shown on Figure 6-1, the extent of the APSI is generally consistent with the background boundary, with the exception of the western side of the area within the background boundary, where concentrations of zinc and copper are generally below the corresponding UTLs. In this area, the extent of the APSI appears to be smaller than the area defined by the background boundary.

Arsenic and lead encountered in areas where concentrations of copper and zinc are below the respective UTLs are generally expected to be either naturally occurring or the result of non-site-related activity (for example, pesticide application, lead paint, etc.). This is because this study determined that the former mine- and smelter-related impacts, for the most part, are characterized by the above-UTL concentrations of zinc and copper (not arsenic and lead because their concentrations could be elevated due to other non-site-related sources). While assessment of potential site impacts and identification of the APSI should be considered in the remedial decisions for this Site, it is not intended to guide the remedial efforts. Actual areas requiring remediation will be identified after the completion of the RI and with consideration of the human health and ecological risk assessments.

6.3 Screening Levels

The concentration of chemicals detected in site media were compared to the preliminary screening levels presented in Tables 6-2 through 6-6, to identify potential COIs and delineate their extent for soil, sediment, surface water, groundwater, and ambient air, respectively. Screening levels are intended to provide a perspective for identifying the nature and extent of contamination; they are not intended to infer the existence or absence of unacceptable risk, since they do not address cumulative risk or consider contributions from background levels. Rather, the risk assessments conducted as part of this RI (Sections 9 and 10) provide site-specific estimates of risk intended for management decision making. The screening levels for the different site media are described below.

6.3.1 Soil

The soil screening levels were identified using the EPA Regional Screening Levels (RSLs) (EPA, 2015a) for residential soil exposures. RSLs are risk-based concentrations derived from standardized equations combining default exposure information assumptions with toxicity data. The RSLs presented equate to a 1 x 10^{-6} risk for carcinogens or a hazard quotient (HQ) of 1.0 for noncarcinogens (EPA, 2015a). Lead concentrations in soil are screened against both the residential RSL of 400 mg/kg and a provisional residential RSL of 140 mg/kg (EPA, 2015a). It should be noted that the provisional screening value has not been fully promulgated by EPA and is currently under review (refer to Section 9.6.3 for further discussion).

The arsenic screening level incorporates site-specific bioavailability (Section 9.4.5 and Appendix H) and corresponds to 1 x 10^{-4} risk. As discussed above, screening levels were developed to identify the nature and extent of contamination; they are not intended to infer the existence or absence of unacceptable risk, since they do not address cumulative risk or consider contributions from background levels.

As discussed in Section 6.2 and presented in Table 6-1, background concentrations were determined for metals using the 95/95 UTL of shallow soil samples, defined as a top depth of 0 feet bgs, collected from areas outside of the background boundary (see Figure 6-1). Surface and subsurface soil concentrations were compared to these background concentrations as part of the nature and extent evaluation. Table 6-2 provides a comparison of the screening level (residential RSL) and the background concentration. Potential COIs were identified as parameters with soil concentrations that exceed both the screening level and background concentration, where developed.

6.3.2 Sediment

The sediment screening levels come from benchmarks that are commonly intended to address potential toxicity to benthic organisms that exist in aquatic habitats. The screening levels are the lowest of the threshold effects concentration, probable effects concentration, and upper effects threshold concentration reported by MacDonald et al. (2000) and Buchman (2008); EPA Region 3 Freshwater Sediment Screening Benchmarks (EPA, 2011c); and the U.S. Department of the Interior (USDI) low effect level of selenium (USDI, 1998). The Agua Fria River is the primary surface water feature in the valley and is the only true aquatic habitat in the APSI. Chaparral Gulch and Galena Gulch are intermittent drainages, and are not covered with water a sufficient amount of time to support aquatic/benthic organisms. Consequently, Chaparral Gulch and Galena Gulch are addressed as terrestrial habitat in the ERA (Section 10). For the specific purpose of evaluating the nature and extent of contamination, all samples historically identified as sediment (whether transitory or permanent) were conservatively screened using sediment benchmarks, including those samples collected from intermittent surface water features, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways on or near the former Humboldt Smelter and Iron King Mine properties. Although these samples were primarily collected in areas designated as terrestrial habitats, screening using criteria for the protection of benthic organisms was conducted as a conservative approach to assess the potential for contaminant migration, as Chaparral Gulch and Galena Gulch discharge to the downstream reaches of the Agua Fria River.

It also should be noted that the sediment screening levels are, in a number of cases, significantly lower than the surface soil background concentrations. For example, the sediment screening level for arsenic is 9.79 mg/kg, while the surface soil background concentration is 112 mg/kg; and the sediment screening level for copper is 31.6 mg/kg, while the surface soil background concentration is 182 mg/kg. Background concentrations were not established for sediment in the *Soil Background Study Report* (CH2M, 2015). Instead, sediment concentrations in the nature and extent evaluation are compared to samples collected upstream from the site source areas. As discussed previously, screening levels were used solely to provide a perspective for identifying the nature and extent of contamination; they are not intended to infer the existence of unacceptable risk. Rather, the risk assessments (Sections 9 and 10) provide site-specific estimates of risk to human and ecological receptors.

6.3.3 Surface Water

The surface water screening levels were selected as the lowest of the ambient water quality criteria for protection of aquatic life. Chronic toxicity benchmarks were used for screening levels and were obtained from ADEQ (2009), NRWQC (EPA, 2009d), and Suter and Tsao (1996) (see Section 10). For water quality goals that vary with hardness, a conservative assumption of a default hardness of 100 mg/L as calcium carbonate ($CaCO_3$) was assumed for this screening-level assessment. A more detailed evaluation using site-specific hardness values for the Agua Fria River was conducted in the risk assessment in Section 10. As a conservative approach for identifying COIs and for the nature and extent evaluation, water quality goals for dissolved metals concentrations were converted to goals for total metals if screening levels for total metals were not available.

As was done for sediment, all samples historically identified as surface water samples (whether transitory or permanent) were conservatively screened using surface water benchmarks, including samples collected from intermittent surface water features, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways on or near the former Humboldt Smelter and Iron King Mine properties. As discussed for sediment, the Agua Fria River is the only true aquatic habitat in the APSI. The Chaparral Gulch and Galena Gulch are intermittent drainages, and are not covered with water a sufficient amount of time to support aquatic/benthic organisms. Screening using water quality goals for protection of aquatic life was conducted as a conservative approach to assess the potential for contaminant migration, as Chaparral Gulch and Galena Gulch discharge to the downstream reaches of the Agua Fria River.

As discussed in Section 5.3.5, no drinking water intakes are known to exist in the Agua Fria River within 15 miles downstream of Chaparral Gulch (ADEQ, 2006). As of 2007, there were no reported surface water diversions for municipal, industrial, or agricultural use in the Agua Fria River Basin (ADWR, 2009, Table 5.1-8). For these reasons, surface water concentrations were not screened against drinking water criteria. The HHRA (Section 9) assesses site-specific risk given current and possible future exposure routes. The use of ambient water quality criteria is a conservative approach and deemed adequate for identifying surface water COIs and evaluating the nature and extent of contamination.

6.3.4 Groundwater

The groundwater screening levels included EPA primary MCLs, EPA secondary MCLs, Arizona Aquifer Water Quality Standards, and EPA tap water RSLs that equate to a 1 x 10^{-6} risk for carcinogens or an HQ of 1.0 for noncarcinogens (EPA, 2015a). Secondary MCLs, Arizona Aquifer Water Quality Standards, and tap water RSLs were used for chemicals that do not have primary MCLs. For metals results, both total and dissolved concentrations were compared to the screening levels, and analytes were retained as potential COIs if either the total or dissolved fraction exceeded thresholds.

6.3.5 Ambient Air

The residential RSLs (EPA, 2015a) were used as screening levels for ambient air concentrations, and equate to a 1 x 10^{-6} risk for carcinogens or an HQ of 1.0 for noncarcinogens.

Residential RSLs are not available for trivalent or total chromium; screening levels are only available for hexavalent chromium. The ambient air samples have not been speciated, but rather were analyzed only for total chromium. To provide some indication of the portion of total chromium occurring in the hexavalent form, soil samples collected from the primary source areas subject to fugitive dust emissions at the former Iron King Mine and Humboldt Smelter properties have been analyzed for both total and hexavalent chromium. Hexavalent chromium has been detected infrequently in these samples (only 3 of 28 usable sample results) and at significantly lower concentrations than total chromium (for example, 18 mg/kg [maximum] hexavalent chromium versus 1,790 mg/kg [maximum] total chromium). Over 96 percent of total chromium is not in the more toxic hexavalent form. Ambient air concentrations of chromium are assumed to be present predominantly in the less toxic trivalent form. Therefore, it is not appropriate to apply the hexavalent screening levels for ambient air. Rather, the risk assessment summarized in Section 9 provides site-specific estimates of risk for all constituents, including chromium.

6.4 Chemicals of Interest

Chemicals detected onsite with concentrations that are equal to or greater than screening levels (see Tables 6-2 through 6-6), and equal to or greater than background concentrations, where developed (see Table 6-1), are considered potential COIs. The list of COIs was further refined to identify primary COIs that will be the focus of the nature and extent evaluation (see Table 6-7). Primary COIs for each media were selected with consideration of the following:

- Frequency of detection above screening levels
- Maximum concentrations relative to screening levels
- Distribution at the former Iron King Mine and Humboldt Smelter properties and adjacent areas

The results of the screening process for soil, sediment, surface water, groundwater, and ambient air are summarized in Tables 6-2 through 6-6. Table 6-7 summarizes the consolidated list of potential COIs for each of these media, and highlights the primary COIs that were selected for the nature and extent evaluation.

6.4.1 Soil

The potential COIs for soil include metals, cyanide, dioxins and furans, PAHs, PCBs, pesticides, and SVOCs (Table 6-2), as follows:

- Metals detected at concentrations that exceeded soil screening levels are: aluminum, antimony, arsenic, cadmium, hexavalent chromium, cobalt, copper, iron, lead, manganese, mercury, silver, thallium, and zinc. The metals that exceeded screening levels also exceeded the site-specific background concentrations for shallow soil, where background concentrations were calculated (see Table 6-2). Lead and arsenic were detected at concentrations exceeding the respective screening levels in a relatively large number, 20 to 70 percent, of samples from the former Iron King Mine and Humboldt Smelter source areas. The concentrations of these constituents also exceeded the respective screening levels in the offsite residential and other areas. The maximum concentrations of arsenic and lead were approximately two orders of magnitude greater than the respective screening levels (Table 6-2). In contrast, the other metals were detected less frequently and at lower concentrations (relative to screening levels).

- PCBs, cyanide, pesticides, and PAHs also have been detected at concentrations exceeding screening levels (Table 6-2), but these exceedances were infrequent and limited to only a few locations at the former Iron King Mine and/or Humboldt Smelter properties. Therefore, the distribution of these contaminants does not appear to be representative of the sitewide soil contamination.
- Dioxin congeners at concentrations exceeding screening levels have been detected only in soil on the former Humboldt Smelter property.

Based on the above, arsenic and lead appear to be the most prevalent contaminants at the Site, because they have the highest frequency of detection above the respective screening levels, highest maximum concentrations relative to screening levels, and the largest distribution at the former Iron King Mine and Humboldt Smelter properties as well as offsite areas. In addition, the distribution pattern of these constituents is generally consistent with the distribution of other potential COIs. Consequently, arsenic and lead are considered the primary COIs for evaluating the nature and extent of the sitewide soil contamination (Table 6-7). In addition, although not primary COIs, zinc and copper are also used as key indicators for evaluating the nature and extent of sitewide soil contamination and the fate and transport of tailings because, together with lead, they are diagnostic of materials being from either the former Iron King Mine or Humboldt Smelter.

6.4.2 Sediment

The potential COIs for sediments also include metals and dioxins (Table 6-3). Dioxin congeners were analyzed in a limited number of sediment samples from the Chaparral Gulch and Agua Fria River near the former Humboldt Smelter property; the maximum detections were in the Tailings Floodplain. The metals detected at concentrations exceeding the respective sediment screening levels were aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, vanadium, and zinc. Of these metals, arsenic, copper, lead, mercury, and zinc had the highest frequency of screening level exceedances (96 percent of arsenic concentrations detected in sediment samples exceeded the conservative screening levels for protection of benthic organisms); they occurred at the highest concentrations relative to the screening levels (two orders of magnitude higher or more); and their distribution was consistent with the distribution of other potential sediment COIs. Consequently, these metals are representative of the sediment contamination sitewide and are considered to be the primary COIs for evaluating the nature and extent of sediment impacts (Table 6-7).

6.4.3 Surface Water

The potential COIs for surface water include metals and cyanide (Table 6-4). The total or dissolved metals detected at concentrations that exceed the respective surface water screening levels are aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc. Although background concentrations in surface water have not been formally determined, concentrations of some metals exceeded the screening levels in a large number of samples and had comparable concentrations both upstream and downstream of the former Iron King Mine and Humboldt Smelter source areas, suggesting the potential for elevated concentrations in ambient water quality. As an example, 95 percent of samples exceeded screening levels for barium, including all samples collected from upstream reaches of the Agua Fria River. Most of the flow in the Agua Fria River upstream of the Town of Dewey-Humboldt consists of effluent from the Prescott Valley Wastewater Treatment Plant (ADEQ, 2009). In addition, there are upstream agricultural uses (see Figure 5-16A), and the local geology results in elevated mineralization in soils and in the alluvial washout from these areas.

Cyanide has been detected in approximately 20 percent of the surface water samples at concentrations that exceed screening levels. The highest cyanide concentrations were detected in surface water samples collected from retention ponds in the NAI operations area and are not representative of surface water impacts to the main drainages (Agua Fria River, Chaparral Gulch, and Galena Gulch). Cyanide concentrations of samples collected within the Agua Fria River and Chaparral Gulch only slightly exceed the screening level (by a factor of 2 or less). Based on the frequency of exceedances and distribution of these exceedances relative to the former Iron King Mine and Humboldt Smelter source areas (for example, concentrations downstream versus upstream of the source areas), arsenic, copper, iron, lead, and zinc are considered representative of the sitewide impacts to surface water (Table 6-7). Although there is not a screening level for sulfate, it is also evaluated as an indicator of mining-related impacts (such as ARD).

6.4.4 Groundwater

The potential COIs in groundwater include metals, TDS, major anions, and explosive compounds (Table 6-5). Groundwater samples collected from EPA monitoring wells, installed on or near the former Iron King Mine and Humboldt Smelter properties, and supply wells in the vicinity of the Site were compared to groundwater screening levels, which included primary and secondary MCLs and tap water RSLs. In general, results for total and dissolved metals in groundwater are available for the EPA monitoring wells, and total metals are available for supply wells. The potential COIs that exceeded screening levels were as follows:

- The dissolved metals that exceed the respective screening levels are aluminum, antimony, arsenic, cadmium, cobalt, iron, lead, manganese, selenium, and zinc. Of these metals, dissolved arsenic and manganese concentrations exceeded screening levels most frequently (in 38 and 47 percent of samples from EPA monitoring wells, respectively); lead concentrations exceeded screening levels in only 3 percent of samples from EPA monitoring wells. Note, that manganese does not have a primary MCL; the screening level used for manganese is the secondary MCL, which is based on aesthetic impacts (color and taste) and staining, rather than potential human health impacts.
- The following additional metals exceeded screening levels based on the total fraction only: beryllium, chromium, copper, mercury, nickel, thallium, and vanadium. The majority of the total metal exceedances were detected in samples collected on July 29, 2014, from EPA monitoring wells, and could be attributable to turbidity effects from these wells (for example, if the wells were not adequately purged before sampling).
- Other inorganic constituents such as TDS and major anions (chloride, nitrate, and sulfate) also exceeded their primary or secondary MCLs in groundwater by an order of magnitude or more. Nitrate was detected at concentrations as high as 360 mg/L, which is significantly higher than the primary MCL of 10 mg/L.
- Explosive compounds (2,4-dinitrotoluene, 2,6-dinitrotoluene, nitrobenzene, and nitroglycerin) were detected in one sample from Iron King Mine well MW-5S at concentrations that exceed residential tap water RSLs. These detections are localized and do not appear to be representative of groundwater impacts sitewide.

Based on the frequency of exceedances of the respective screening levels and distribution of these parameters, the primary COIs for groundwater are arsenic, lead, nitrate, sulfate, and TDS (Table 6-7). TDS, sulfate, and chloride also can serve as indicators of potential groundwater impacts associated with the former Iron King Mine and Humboldt Smelter properties because of the elevated concentrations of these constituents onsite and their conservative (mobile) nature (these constituents do not readily attenuate and can serve as tracers representing contaminant migration in groundwater).

6.4.5 Ambient Air

As a conservative approach for identifying COIs, screening levels were compared to the maximum detected concentration in ambient air samples collected using either the BGI PQ100 or the continuous particulate monitors (TEOM samplers). As discussed in Section 6.1.3, the TEOM samplers were intended to characterize high wind events, and were biased to only include sampling when specified TSP thresholds were exceeded. As discussed in Section 6.3, screening levels were used solely to provide a perspective for identifying the nature and extent of contamination, and are not intended to infer the existence of unacceptable risk. Aluminum, arsenic, beryllium, cadmium, lead, and nickel exceeded screening levels in samples of ambient air and are considered potential COIs (Table 6-6). Of these COIs identified, arsenic exceeded its screening level most frequently (approximately 20 percent of samples) (Table 6-7).

6.5 Indicator Metal and Ratio Methodology

This section summarizes the methodology and rationale for the statistical analysis of key metals (lead, copper, and zinc) and their ratios (lead to copper [Pb:Cu] and zinc to copper [Zn:Cu]) that are used to evaluate the fate and transport of tailings from the former Iron King Mine and Humboldt Smelter properties. These metals and ratios are diagnostic of materials being from either the Iron King Mine or Humboldt Smelter. The statistical analysis of the metals and ratios is presented in Appendix I.

The objective of the statistical analysis was to assess whether Iron King Mine tailings or Humboldt Smelter tailings sediment mixtures have accumulated in the Tailings Floodplain upstream of the Chaparral Gulch Dam. The results from this analysis are primarily used to evaluate the fate and transport of contaminants and the formation of the Tailings Floodplain (Section 8.4).

Potential transport mechanisms of tailings to the Chaparral Gulch floodplain include the following:

- Direct discharges of water with high particulate loads during historical operations on the former Iron King Mine and Humboldt Smelter properties
- Direct releases of tailings associated with failures of tailings impoundments, including the MTP 1964 Blow Out and breaches of the Smelter Tailings Swale berm
- Erosion of tailings and downstream sediment transport to and within Chaparral Gulch
- Accumulation of windblown tailings in the watersheds and subsequent erosion and downstream sediment transport to and within the gulch

The differentiation of tailings from the former Humboldt Smelter and Iron King Mine properties based on physical characteristics (color for example) or metals concentrations are complicated by mixing, redeposition, and other sediment transport processes, which can alter these characteristics and make determination of the tailings origin difficult. Therefore, a statistical comparison of key geochemical properties was evaluated for use in differentiating the tailings, in addition to an evaluation of key metals concentrations alone (lead, copper, and zinc). Specifically, the Pb:Cu and Zn:Cu concentration ratios were calculated from materials sampled within the Tailings Floodplain and were used to assess whether Iron King Mine tailings have contributed to these deposits behind the dam, in addition to tailings from the Humboldt Smelter.

Iron King Mine exploited a massive sulfide deposit that primarily produced lead and zinc (but also some copper), and the concentrations of these two metals remain elevated in the Iron King Mine tailings compared to concentrations of copper. The Humboldt Smelter processed copper, and the Humboldt Smelter tailings are concentrated in copper relative to other metals, including lead and zinc.

Consequently, ratios of lead to copper (Pb:Cu) and zinc to copper (Zn:Cu) concentrations were used for the comparative statistical analysis of the samples from these sources and the hydrostratigraphic groupings for Chaparral Gulch. In addition to high lead and zinc concentrations, a high Pb:Cu ratio and high Zn:Cu ratio could be used in a weight-of-evidence approach to show that the material in question likely originated from the Iron King Mine tailings. Conversely, relatively low lead and zinc concentrations, and low Pb:Cu and Zn:Cu ratios, would indicate that the material may have originated from the Humboldt Smelter tailings, from upstream channel deposits, or from a mixture of these materials. Significant mixing with non-Iron King Mine materials could dilute the Iron King Mine signature to the point that it may not be recognizable, even though there may be low percentages present.

The analysis was performed for the six unconsolidated units overlying the Hickey Formation that were observed and mapped in the subsurface within and adjacent to the Chaparral Gulch channel and Tailings Floodplain as part of the ERT data gap investigation (Lockheed Martin SERAS, 2015) listed below. A full description of these units is found in Section 5.4.3.

- Uppermost Channel Deposit (UCD)
- Tailings
- Humboldt Smelter Channel Deposit (HSCD)
- Lowermost Channel Deposit (LCD)
- Brown Clay
- Principal Fluvial Gravels (PFG)

ERT's interpretation indicated that the UCD, HSCD, and LCD units consisted of mixed tailings and fluvium based on their stratigraphic position, physical characteristics, and elevated metals concentrations (Lockheed Martin SERAS, 2015). The Brown Clay and PFG are interpreted to be native alluvium that was present before the Iron King Mine and Humboldt Smelter began operations, and therefore are generally not considered to be impacted by site contamination. Any tailings from either the Iron King Mine or Humboldt Smelter would overlay the Brown Clay and PFG. Both undisturbed and reworked (such as redeposited and mixed) tailings have been observed in the subsurface of Chaparral Gulch (see Section 5.4 for a description of the units, as well as a more detailed discussion in Section 7.2.3).

Analytical data for the tailings samples collected from the former Iron King Mine and Humboldt Smelter, as well as the UCD, LCD, HSCD and other unconsolidated deposits in Chaparral Gulch upstream of the dam, were compiled and categorized by unit or material. The following statistical procedures were used to evaluate the origin of tailings in each unit, using primarily data collected in 2014 as part of the ERT data gap investigation, but also some samples from 2008:

- **Wilcoxon-Rank Sum Comparison.** The Wilcoxon Rank Sum method is used to compare two samples and to determine if they are drawn from populations with different means (Gilbert, 1987). The method was used to assess whether the Pb:Cu and Zn:Cu ratios for Iron King Mine tailings and Humboldt Smelter tailings are significantly different and useful for differentiating sources.

- **Box and Whisker Plots.** Box and Whisker Plots provide a visual idea of central tendency, variability, and skewness of each dataset for comparison (Swan and Sandilands, 1995). The plots were used to assess differences in the concentrations of lead, copper, and zinc; the concentration ratios between the Iron King Mine and Humboldt Smelter; and potential influence of one source over another in mixtures (that is, geologic groupings for Chaparral Gulch).

- **Normality Quantile Plots.** The Normality Quantile Plot is commonly used in testing the normality of a sample set, with a perfectly normal distribution plotting as a straight line (Gilbert, 1987). The Normality Quantile Plots were used to infer differences among the sample groupings and the degree of contribution (mixing) between sample groups based on distribution of the Pb:Cu and Zn:Cu ratios.

In addition, cross plots of zinc concentrations versus lead and copper concentrations and the ratios of Pb:Cu and Zn:Cu were prepared to assess the relative differences across different material types. Cross plots were prepared with all materials on one plot; separate plots were also prepared with Iron King Mine data compared to each of the other material types to aid in this analysis.

A detailed discussion of the statistical methodology used in the study is contained in Appendix I. The findings of the study for each of the units within the Tailings Floodplain are also contained in Appendix I and are discussed further in Section 8.4, which presents a weight-of-evidence approach to differentiate the sources of tailings in the floodplain.

6.6 Exposure Areas

For the purpose of this RI, sample results were grouped by media to evaluate the nature and extent of Site impacts. The nature and extent of COIs in sediment, surface water, ambient air, and groundwater were generally evaluated on a sitewide basis. For soil, however, EPA subdivided the Site into separate exposure areas for both the nature and extent evaluation and the risk assessments (HHRA and ERA; see Sections 9 and 10). This section discusses the development of exposure areas, beginning with a conceptual presentation of the sources of contamination and focus areas of the Site, and ending with a more detailed presentation of the individual exposure areas.

6.6.1 Sources of Contamination and Focus Areas of the Site

Historical mining and smelting activities resulted in the formation of numerous waste piles. Substantial source areas on the former Iron King Mine property include tailings, primarily in the MTP, and waste rock, primarily in the former Mineworks and former Fertilizer Plant areas. Source areas on the Humboldt Smelter property include the Smelter Tailings Swale and Tailings Floodplain, smelter slag piles, and dross. In addition, a tailings deposit is located along the Agua Fria River that is likely a result of predecessor mining and milling operations. These source areas are shown on Figure 6-2.

Contamination migrated from these sources areas via a number of release and transport pathways. The largest known tailings release event occurred during the MTP 1964 Blow Out. Other notable release and transport pathways include the following:

- Historical operational discharges
- Impoundment failures
- Placement of mine and smelter waste in drainages or on nearby properties
- Erosion during storm events
- Spills during transport along rail routes
- Historical smelter stack emissions
- Windblown particulates, including tailings, dross, and contaminated soil
- Use of mine waste material as fill material or road base and redistribution of contamination during development

As discussed in Section 6.2, the soil background study performed as part of the RI (see Appendix E) was used to define the APSI shown on Figure 6-2. Shallow soil sampling was conducted on residential properties located within the APSI to characterize the nature, extent, fate, and transport of Site impacts to these areas via the mechanisms listed above, and to characterize human health risks. Two types of investigations were performed: (1) yard-by-yard sampling, and (2) evaluation of screening areas (see Figure 6-2). In total, approximately 6,300 soil samples were collected from residential properties within the APSI.

6.6.2 Development of Exposure Areas

EPA used the conceptual understanding of the Site (Figure 6-2) to subdivide it into distinct areas based on current or future land use, former operations, waste types/source materials, and property boundaries. For the purposes of both the nature and extent evaluation and the risk assessments, these defined areas are referred to as "exposure areas." Figure 6-3 shows the locations of the exposure areas. Table 6-8 provides a summary of the areas.

As shown on Figure 6-3, each of the exposure areas for soil was given one of four designations based on current or potential future land use:

1. Non-Residential: Includes properties currently zoned for industrial, commercial, or recreational uses, or that are undeveloped and unlikely to be developed for residential use in the future.
2. Non-Residential/Possible Future Residential: Includes properties that are currently vacant or have a non-residential use, but could be rezoned and/or developed for residential use in the future.
3. Residential Yard-Specific Risk (RYSR): Residential properties sampled and evaluated on a yard-by-yard basis.
4. Residential Screening Area Risk (RSAR): Residential properties sampled and evaluated by screening areas, rather than individual yards.

It should be noted that the exposure area designations in this RI Report differ from designations in the Initial RI report (EA, 2010), but more accurately represent differences in land use, operations, source materials, and property boundaries. As an example, the Initial RI report defined "Upper Chaparral Gulch" as the portion of the gulch upstream from Highway 69, north of the MTP. For purposes of the nature and extent evaluation and risk assessments, the exposure areas in this RI Report define "Upper Chaparral Gulch" as the section east (downgradient) of Highway 69 to the Third Street overcrossing.

The ERA uses slightly different exposure areas that reflect habitat areas and the range of wildlife, and excludes developed areas in Humboldt Proper. Refer to Section 10 for further discussion of the exposure areas used for the baseline ERA.

The following subsections provide a description of the individual soil exposure areas as well as the sitewide media.

6.6.3 NR2 Dewey-Humboldt Town Hall

NR2 is split into two segments: Dewey-Humboldt Town Hall (discussed here) and Humboldt Elementary School (discussed in the next section). The first portion of NR2 is a series of commercial buildings in Humboldt Proper that includes the Dewey-Humboldt Town Hall and a parking lot. Most of the exposure area is covered with asphalt. This area is not residential.

6.6.4 NR2 Humboldt Elementary School

The second portion of NR2 is the Humboldt Elementary School, the only school in Humboldt Proper. Other schools in the Humboldt Unified School District include Bradshaw Mountain Middle School, located in Dewey Proper north of the intersection of Highways 69 and 169, and Bradshaw Mountain High School, located in Prescott Valley. The Humboldt Elementary School grounds are primarily covered by buildings or paved surfaces; however, unpaved play fields and open soil areas occur at the school.

6.6.5 NR3 Upper Chaparral Gulch

NR3, the Upper Chaparral Gulch exposure area, encompasses the Chaparral Gulch channel and a widening channel floodplain between Highway 69 and Third Street. The current conceptual model suggests that Upper Chaparral Gulch (NR3) is impacted by tailings from the former Iron King Mine operations and releases, north of Highway 69, which were transported under the highway culvert. Periodic weather events also brought significant amounts of alluvial materials from higher elevations that have deposited at this location and points further downstream; this is evident by a comparison of Photograph 10 in Appendix A with current conditions. The photograph was taken in 2008 and shows a series of culverts where Chaparral Gulch crosses Third Street. Currently, Third street pavement is flush with soils in this floodplain, and no bridge or culvert structures are evident. Long-time residents in the area communicated to EPA that the surface of Chaparral Gulch at Third Street used to be 6 to 10 feet lower 20 to 30 years ago.

The Upper Chaparral Gulch exposure area overlaps adjacent residential properties. The confluence of Chaparral Gulch with the MTP 1964 Blow Out Path (NR5) occurs just downstream of the NR3 exposure area.

6.6.6 NR4 JT Septic Facility

NR4, JT Septic, is a commercial facility located east of the MTP and Highway 69. The current conceptual model suggests that a portion of the tailings (likely finer-grain-size) released by the MTP 1964 Blow Out discharged under the current location of Highway 69 and into the JT Septic property. Sections 2.1 and 2.3 discuss the 1964 Blow Out in more detail. The JT Septic Facility (NR4) is not residential.

6.6.7 NR5 Main Tailings Pile 1964 Blow Out Path

As discussed under NR4, the current conceptual model suggests that a portion of the tailings released by the MTP 1964 Blow Out discharged under the current location of Highway 69, into the JT Septic property (NR4), across what is now Third Street, and into a gulley that runs east, parallel to Third Street, before merging downstream with Chaparral Gulch. This gulley area is termed NR5 and is not residential.

6.6.8 NR6 Middle Chaparral Gulch

NR6, Middle Chaparral Gulch, extends from the Third Street overcrossing downstream to the western edge of the Humboldt Smelter Swale, where the Tailings Floodplain (NR8) begins. The current conceptual model suggests that Middle Chaparral Gulch (NR6) is impacted by tailings from the former Iron King Mine operations and releases north of Highway 69, which were transported under the highway culvert and through Upper Chaparral Gulch (NR3), as well as tailings discharged through NR4 and NR5 during the MTP 1964 Blow Out. This area is not residential.

6.6.9 NR7 Smelter Tailings Swale

The Smelter Tailings Swale is a bermed tailings impoundment located on the former Humboldt Smelter property, and is topographically lower and west of the former Pyrometallurgical Operations area (NR11) and the Smelter Plateau (NR12). This area was used to store or dispose of tailings that were produced as a waste product from concentrating ore to prepare copper concentrate to feed the smelter. The berm, visible across the bottom of the swale (Figure 2-2), failed, releasing tailings into the Tailings Floodplain (NR8). More information regarding the Smelter Tailings Swale is presented in Section 2.1.3.6.

6.6.10 NR8 Tailings Floodplain

The Tailings Floodplain (NR8) is located on the former Humboldt Smelter property, downstream of Middle Chaparral Gulch (NR6), and extends from the southern boundary of the Smelter Tailings Swale (NR7) to below the Chaparral Gulch Dam (Figure 2-2 and Figure 6-3). Impoundment failures and historical discharges from both the former Iron King Mine and former Humboldt Smelter properties have released tailings into Chaparral Gulch, forming the Tailings Floodplain. The Chaparral Gulch Dam impounds tailings and native alluvial deposits, and although the dam restricts groundwater flow in the saturated sediment wedge behind the dam, seepage discharges from the toe of the dam throughout the year. The thickness of these deposits increases downstream toward the dam, where the saturated thickness exceeds 20 feet. Little or no storage capacity remains behind the dam because of the accumulation of tailings and alluvium, which can now continue to migrate downstream to the Agua Fria River. More information regarding the Tailings Floodplain is presented in Section 2.1.3.6.

6.6.11 NR9 Lower Chaparral Gulch

Lower Chaparral Gulch (NR9) is located downstream of the Tailings Floodplain (NR8) and Chaparral Gulch Dam and extends to the confluence with the Agua Fria River. This reach of the gulch is a narrow steep-walled canyon, part of which is located on the former Humboldt Smelter property. Groundwater within the deposits behind the dam seeps beneath or around the dam abutments, providing a low but continuous surface water flow to Lower Chaparral Gulch, sustaining riparian habitat in this reach (see Section 5.6). Tailings deposits are visible in the lower Chaparral Gulch canyon, approximately 800 feet downstream of the Chaparral Gulch Dam and upstream of its confluence with the Agua Fria River (Figure 2-2), that were likely associated with precursor operations, or possibly discharges of tailings from upstream operations.

6.6.12 NR10 Agua Fria Tailings Pile

The Agua Fria Tailings Pile, NR10, contains a localized area of tailings that were likely tremied or slurried from predecessor mining and milling operations occurring in the late 1800s (see Sections 2.1 and 2.3). The tailings are located in the southeast corner of the former Humboldt Smelter property, within a canyon incised by the Agua Fria River, and extend into the 100-year flood plain of Agua Fria River (see Section 5.3).

6.6.13 NR11 Former Pyrometallurgical Operations Area

NR11, the former Pyrometallurgical Operations area, encompasses the portion of the former Humboldt Smelter property where the majority of the smelting operations occurred. Historical Pyrometallurgical Operations included handling of ore concentrate and molten materials and operation of roasters, blast and reverberatory furnaces, and converters. Cooling ponds and many other historical features were also located in this area (Figures 2-2 and 2-3). Smelter slag, consisting of blocks and sheets of vitrified material, were dumped or placed onsite, and have formed a steep bluff overhanging the Agua Fria River. Slope failures have occurred, and slag extends down to the edge of the Agua Fria River in places. After closure and dismantling of the Humboldt Smelter, a large quantity of dross was imported for reprocessing to recover aluminum and zinc. The dross occurs as thin veneer and in piles and covers most of the exposure area (Figure 6-2). More information on the former Pyrometallurgical Operations area, slag piles, and dross is presented in Section 2.1.3; more information on the Humboldt Smelter operations is presented in Section 2.3.3.

6.6.14 NR12 Smelter Plateau

The Smelter Plateau (NR12) is the portion of the former Humboldt Smelter property that lies on the basalt plateau, south of the former Pyrometallurgical Operations area (NR11). The plateau is surrounded by downslope areas, including the Smelter Tailings Swale (NR7), Tailings Floodplain (NR8), Lower Chaparral Gulch (NR9), the Agua Fria Tailings Pile (NR10), and the Agua Fria River (Figure 6-3). Precursor mining operations, residential housing during smelting operations, and ancillary smelting and dross operations were present in this area. Sporadic piles of dross and tailings are currently exposed on the plateau, and a second (satellite) slag pile is located along the eastern boundary of the exposure area, upslope from the Agua Fria River (see Figure 2-2).

6.6.15 NR13 Former Humboldt Smelter Property East of the Agua Fria River

NR13 includes the undeveloped portion of the former Humboldt Smelter property east of the Agua Fria River, as well as adjacent undeveloped land. NR13 is located across from the primary slag pile, on a plateau above the Agua Fria River canyon. This land is currently vacant, but could be developed for residential use in the future.

6.6.16 NR14 South of Former Iron King Mine Property

NR14 adjoins the southern boundary of the former Iron King Mine property, south and downslope of the MTP and former Mineworks area. NR14 is within the Galena Gulch watershed; other ancillary drainages emanating from Iron King Mine enter this exposure area. The area is vacant and undeveloped. Plates of the underground mine workings show that the workings extend southwest of the former Iron King Mine property boundary through NR14 at depths of 100 to 800 feet. Two of the primary shafts (Shafts 1 and 5) and associated waste dumps are located along bedrock benches and adjoining slopes of Galena Gulch in the area south of the former Fertilizer Plant (Figure 2-1) (Lockheed Martin SERAS, 2015). This is the same area where, in 2014, ERT identified waste rock, three abandoned mine shafts, and one small horizontal portal. This area could plausibly be rezoned and developed for residential use.

6.6.17 NR15 Auto Yard

NR15 is the auto dismantling yard operated by Iron King Auto Salvage. NR15 is located adjacent to and south of the former Iron King Mine property and MTP (NR17) and east of NR14. This area is not residential.

6.6.18 NR16 Former Mineworks Area

NR16 is the former Mineworks area and is located in the southwestern portion of the former Iron King Mine property. The former Mineworks area included the mine headworks, shafts, ore concentrating equipment, and numerous mine buildings. Waste rock associated with former mining operations is present over a large portion of the former Mineworks area and occurs in piles and as a veneer. A pile of waste rock was also placed west of the Iron King Mine property along the northern bank of Galena Gulch (Figure 2-1) (Lockheed Martin SERAS, 2015).

The exposure area also includes the former Fertilizer Plant area (see Figure 2-1). Currently, the former Fertilizer Plant area is mostly covered by waste rock surface deposits and tailings, as well as abandoned buildings, pads, sumps, tanks, and an ore bin.

More information on the former Mineworks and former Fertilizer Plant areas is presented in Section 2.1.2.

6.6.19 NR17 Main Tailings Pile

NR17 is the former Iron King Mine MTP. The MTP consists of milled waste (tailings) deposited on the former Iron King Mine property as part of the mining operation. The MTP has an area of about 55 acres and includes an upper tailings pile (upper MTP) that is up to 105 feet thick, and a lower tailings pile (lower MTP) that is up to 60 feet thick (GEI, 2012). The MTP was originally developed as a series of smaller impoundments within two shallow drainages that were tributaries to Chaparral Gulch. Several stormwater retention ponds are used currently to control surface water flow from the MTP (Figure 2-1).

In 1964, during a period of high rainfall, a portion of the southeastern slope of the upper MTP failed resulting in the largest known tailings release event (Kentro, 1964; GEI, 2010), known as the “MTP Blow Out.” A significant portion of the tailings accumulated on the former Iron King Mine property behind a berm created by the historic rail bed west of State Highway 69, forming the lower MTP (Figure 2-1). Some of the released tailings discharged southeast into Chaparral Gulch, through exposure areas NR4 and NR5. More information on the MTP is presented in Section 2.1.2.2.

6.6.20 NR18 North American Industries Operations Area

NR18 is the NAI Operations area on the former Iron King Mine property, adjacent to and north of the MTP (NR17). The NAI Operations area includes fertilizer production buildings, warehouses, and an office that were built starting in 1988 (Figure 2-1). Tailings from the MTP are screened, stockpiled, and processed in this area to produce a liquid fertilizer product called Hydromax. Several stormwater retention ponds are currently used to control surface water flow around the Iron King Mine MTP and NAI Operations area. More information on fertilizer operations is presented in Sections 2.1.2.5 and 2.3.2.1.

6.6.21 NR19 Former Glory Hole and North of Main Tailings Pile

NR19 is located north of the MTP and includes a portion of the former Iron King Mine property (Figure 6-3). NR19 extends north (downslope and downwind) from the former Mineworks area (NR16), MTP (NR17), and NAI Operations area (NR18) to Chaparral Gulch. Iron King Mine operational features in this area include the Glory Hole (collapsed mine workings), which was later used as a construction debris landfill, and the former Small Tailings Pile, which was excavated and consolidated at the MTP in 2011. This exposure area also includes a pile of waste rock north of the Glory Hole, and two former piles of rusted drums thought to contain cyanide (see Section 3.2.1). Despite its current zoning (Figure 5-16B), the area could be rezoned and developed for residential use.

6.6.22 NR20 North of Chaparral Gulch

NR20 is located north (upslope) from NR19, and extends from Chaparral Gulch north to the next ridgeline (Figure 6-3). This ridgeline is thought to have served as a windbreak for windblown tailings migrating north of the former Iron King Mine property. NR20 includes a small portion of the former Iron King Mine property, which is currently zoned industrial, and vacant undeveloped land north of the property boundary that is zoned for limited residential use (Figure 5-16B).

6.6.23 Residential Yard-Specific Risk (RYSR)

Surface soil sampling was conducted on residential properties located within or near the APSI boundary to characterize the nature and extent of Site impacts in these areas and to characterize human health risks. Multiple phases of sampling were performed, with the most extensive sampling efforts occurring between 2008 and 2012, and between 2013 and 2014 (Figure 3-1). In total, approximately 6,300 soil samples were collected from residential properties within the APSI. Sampling was performed at the scale of residential yards (Lockheed Martin SERAS, 2015).

Two sampling approaches were used (Lockheed Martin SERAS, 2015), as follows:

- Properties located closer to the former Iron King Mine or Humboldt Smelter properties, or where previous sampling indicated the presence of elevated concentrations of COIs, were designated as RYSR areas. For RYSR areas, sampling was performed and analytical results were evaluated on a yard-by-yard basis.
- Properties located near the boundary of the APSI that were judged less likely to be impacted by site-related impacts, based on distance from the former Iron King Mine and Humboldt Smelter properties, were designated as RSAR areas. RSAR areas are discussed below in the following section.

For the purpose of RYSR sampling, a yard or property was defined as the area that current or future resident(s) may potentially utilize. The terms yard and property are used interchangeably in this RI Report. In contrast, a parcel is an area of land defined by the Yavapai County GIS database and is associated with an owner (business or person). A yard typically consisted of a single parcel. But in some cases, for the purposes of sampling and risk evaluation, small parcels were locally combined into single yards (for example, in instances where a single dwelling existed on multiple small parcels). Similarly, larger parcels were divided into multiple yards (for example, if multiple residents or tenants had separate dwellings/areas of use on a single parcel). Sampling was performed only at those yards where the property owner (and tenant if applicable) provided EPA access for sample collection. Yards that were sampled were assigned a unique identifier to facilitate tracking of analytical results and assessment of human health risks.

A sufficient number of samples were collected from each RYSR area to estimate the areal average concentration (as represented by the 95 percent UCL of the mean) for that area. This concentration is referred to as the EPC and is primarily used to assess human health risks (see Section 9), but also is used to evaluate the nature and extent of arsenic and lead contamination in residential areas on an exposure-area-specific basis. In general, samples were collected at ground surface (shallow samples) and at a depth of approximately 1 foot bgs (deep samples). Deeper subsurface samples were collected locally if information suggested that contamination might be present at depth. The number of samples collected per yard was based on the yard size, as summarized below:

- Yards less than 1 acre: 10 shallow and 1 deep samples
- Yards 1 to 3 acres: 15 shallow and 2 deep samples
- Yards greater than 3 acres: 20 shallow and 3 deep samples

More specific information on RYSR sampling and analysis is provided in Section 11 of the ERT report (Lockheed Martin SERAS, 2015).

6.6.24 Residential Screening Area Risk (RSAR)

Properties located near the boundary of the APSI that were judged less likely to be impacted by site-related impacts, based on distance from the former Iron King Mine and Humboldt Smelter properties, were designated as RSAR areas. Eight RSARs were identified: RSAR-A though RSAR H. RSAR exposure areas were screened on a per-area basis instead of a per-property basis; therefore, not every property in the area needed to be sampled to attain a statistically significant dataset. A subset of the yards in each RSAR area were randomly selected for sampling, and two to six surface samples (depending on its size) were collected at the selected yard. As discussed under RYSR, EPCs were calculated for RSARs to assess human health risks (see Section 9) and evaluate the nature and extent of contamination on an area-specific basis. For RSAR areas, or parts of RSAR areas, that had elevated EPCs, the area was recategorized as a RYSR and additional sampling was conducted. More specific information on RSAR sampling is provided in Section 11 of the ERT report (Lockheed Martin SERAS, 2015).

As noted on Figure 6-3, within the exposure area designated as RSAR-D, a stormwater diversion berm known to be made using imported mine tailings was identified as a hot spot during field investigations in 2014. As a result, the hot spot area is considered separately from the remainder of RSAR-D in the risk assessment and nature and extent evaluations.

6.6.25 Sediment and Surface Water

Three surface water features transect the Site: the Agua Fria River, Chaparral Gulch, and Galena Gulch. The Agua Fria River is the primary surface water feature in the area and provides the only true aquatic habitat that occurs within APSI boundaries. In the vicinity of the Site, the Agua Fria River is perennial and flows south through portions of the eastern section of the former Humboldt Smelter property. As discussed previously, slag deposits have formed a steep bluff overhanging the Agua Fria River in the section adjacent to or within the former Humboldt Smelter property, and a tailings deposit is located along the river near the confluence with Chaparral Gulch.

Chaparral Gulch and Galena Gulch are intermittent drainages that cut west to east across the Site area. During rain events, these drainages convey surface water runoff to the Agua Fria River. Chaparral Gulch flows southeast through the northern portion of the former Iron King Mine property, under State

Highway 69, and through the southern portion of the former Humboldt Smelter property to the confluence with the Agua Fria River. Chaparral Gulch has been impacted by impoundment failures and historical discharges from both the former Humboldt Smelter and Iron King Mine operations. On the former Humboldt Smelter property, the Chaparral Gulch Dam impounded tailings and alluvium and formed the Tailings Floodplain (NR8) within the gulch channel.

Galena Gulch transects the southwestern portion of the former Iron King Mine property adjacent to the former Mineworks area and the former Fertilizer Plant area. Abandoned mine shafts and areas of waste rock are present on bedrock benches and adjoining slopes along Galena Gulch in the area south of the former Fertilizer Plant.

In addition to the three surface water features, samples historically identified as sediment or surface water include samples collected from ephemeral surface water features, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways on or near the former Humboldt Smelter and Iron King Mine properties. For the purposes of the HHRA and ERA, only the Agua Fria River is considered aquatic habitat; Chaparral Gulch and Galena Gulch are addressed as terrestrial habitat (see Sections 9 and 10). For the specific purpose of evaluating the nature and extent of contamination, all samples historically identified as surface water or sediment (whether transitory or permanent) were conservatively screened against aquatic-based benchmarks.

6.6.26 Groundwater

EPA has installed 26 monitoring wells screened in the alluvium (and tailings), Hickey Formation, and Precambrian bedrock (see Section 5.5 and Table 5-4). Numerous domestic supply wells in the vicinity of the Site also were sampled during pre-NPL investigations and initial phases of the RI (EA, 2010).

6.6.27 Ambient Air

Fine-grained materials (primarily tailings and dross) at the former Iron King Mine and Humboldt Smelter properties are potential sources for ambient air contamination. Air samplers were placed at the former Iron King Mine property, at the former Humboldt Smelter property, in Humboldt proper, and at locations thought to be indicative of background during the 2008 to 2009 Initial RI (EA, 2010).

SECTION 7

Nature and Extent of Contamination

This section describes the nature and extent of contamination found in soils, sediments, surface water, groundwater, and ambient air at the Iron King Mine – Humboldt Smelter Superfund Site. Contaminant sources are primarily associated with:

- Underground mining and the production of ore, waste rock, and waste transmitted by surface discharges and air dispersion at the former Iron King Mine property
- Ore processing, smelting, production of tailings and smelter waste, and air emissions from smelter stacks at the former Humboldt Smelter property
- Release of tailings and other waste materials to the environment at both properties

Releases and transport of contamination resulted from a number of processes, including operational discharges, impoundment failures, placement of mine and smelter waste in drainages or nearby properties, erosion during storm events, spills during transport along rail routes, smelter stack emissions, windblown particulates, and use of mine waste material as fill material and road base.

Site contaminants, primarily metals such as lead and arsenic, have been transported from the mine workings by surface discharges to Chaparral Gulch, Galena Gulch, and the Agua Fria River. Impacted and potentially impacted areas include: (1) the former Iron King Mine and Humboldt Smelter properties, (2) peripheral or undeveloped areas, (3) Galena Gulch, (4) Chaparral Gulch, (5) the Agua Fria River; and (6) non-residential and residential parcels within the Town of Dewey-Humboldt.

As discussed in Section 6.4, the primary COIs include arsenic, lead, copper, and zinc. Other COIs were also identified in some exposure areas.

Section 7 presents chemical and soils data, and analysis of these data, to estimate the distribution of contaminants. Section 8 provides an analysis of the fate and transport of these contaminants.

Section 7 is organized into the following subsections:

- Section 7.1 - overview of the distribution of soil contaminants in non-residential areas on a sitewide basis
- Section 7.2 - distribution of soil contaminants for each exposure area at the former Iron King Mine, the former Humboldt Smelter, Chaparral Gulch, and non-residential areas
- Section 7.3 - distribution of soil contaminants at residential properties
- Section 7.4 - distribution of contaminants in sediment samples (defined as soil particles present in intermittent surface water drainages, ponded areas (dry or wet), retention ponds, and drainage pathways)
- Section 7.5 - data and analysis of surface water contamination (see Section 5.3 for surface water hydrology)
- Section 7.6 - data and analysis of groundwater contamination (see Section 5.5 for hydrogeology)
- Section 7.7 - data and analysis of air quality (see Section 5.2 for meteorology)

Table 7-1 lists the defined exposure areas, affected media, and COIs for each exposure area that exceed screening levels; this table also provides a summary description of the contamination found within each exposure area.

7.1 Sitewide Soil Concentrations in Non-Residential Areas

This section summarizes the distribution of arsenic, lead, copper, and zinc concentrations in soil, and the distribution of other COIs found at the Site, including manganese, iron, thallium, and antimony.

Over 2,200 samples were collected for analytical testing in the non-residential exposure areas, designated with an "NR" prefix in both exposure area designation and for each sample record in the analytical database for the Site. These areas include (1) the former Iron King Mine and Humboldt Smelter properties, (2) peripheral or undeveloped areas immediately adjacent to the properties, (3) Galena Gulch, (4) Chaparral Gulch, and (5) an area adjacent the Agua Fria River.

Figures 7-1 through 7-4 show the sitewide distribution of arsenic, lead, copper, and zinc concentrations in shallow soil, incorporating both older data (used to define the APSI) and more recently collected data. These metals are useful indicators of impacts from source areas at the former Iron King Mine and Humboldt Smelter properties, due to their elevated concentrations. Tables 7-4 through 7-13 provide a summary listing of analytical results for surface and subsurface samples collected throughout the Site.

7.1.1 Sitewide Distribution of Arsenic, Lead, Copper, and Zinc

7.1.1.1 Arsenic

Figure 7-1 shows the sitewide distribution of arsenic in shallow soil, including both pre-RI and RI-collected data. A cursory examination of the figure shows that the maximum arsenic concentrations were found at the greatest frequency in the area of, and adjacent to, the former Iron King Mine. Elevated arsenic concentrations were found in samples downgradient from this area within all segments of Chaparral Gulch and the Tailings Floodplain. Elevated arsenic concentrations also were found in the former Pyrometallurgical Operations area and the Smelter Plateau, albeit at much lower concentrations and frequency.

The average arsenic concentration for 2,206 samples collected in the non-residential (NR) exposure areas equaled 338 mg/kg. Approximately 48 percent of the samples exceeded background for arsenic (112 mg/kg) and 34 percent exceeded the screening level (194 mg/kg). Of the 750 samples that exceeded the screening level, the average arsenic concentration equaled 1,100 mg/kg. Arsenic concentrations exceeded 1,000 mg/kg in 14 exposure areas, and exceeded 10,000 mg/kg in three exposure areas. Section 7.2 provides a detailed description of the arsenic concentrations and distribution within each exposure area.

Exposure areas with the maximum arsenic concentrations and the greatest percentage of samples that exceeded the arsenic screening level are listed below.

Former Iron King Mine MTP and MTP Blow Out Path

- MTP (NR17): all tailings samples exceeded the screening level. The average arsenic concentration for these 79 samples equaled 3,974 mg/kg.
- Former Mineworks Area (NR16): 60 percent of the 104 samples exceeded the screening level. The average arsenic concentration for these samples equaled 1,026 mg/kg.
- JT Septic Facility (NR4): 75 percent of the 9 samples exceeded the screening level. The average arsenic concentration for these samples equaled 1,024 mg/kg.
- MTP 1964 Blow Out Path (NR5): 56 percent of the 63 samples exceeded the screening level. The average arsenic concentration for these samples equaled 599 mg/kg.

Chaparral Gulch

- Middle Chaparral Gulch (NR6): 47 percent of the 168 samples exceeded the screening level. The average arsenic concentration for these samples equaled 632 mg/kg.
- Tailings Floodplain (NR8): 48 percent of the 355 samples exceeded the screening level. The average arsenic concentration for these samples equaled 699 mg/kg.

Humboldt Smelter and Smelter Plateau

- Former Pyrometallurgical Operations Area (NR11): 21 percent of the 319 samples exceeded the screening level. The average arsenic concentration for these samples equaled 709 mg/kg. As discussed in Section 7.2, the results varied between ash piles, tailings, and dross tested in NR11.
- Smelter Tailings Swale (NR7): 24 percent of the 86 samples exceeded the screening level. The average arsenic concentration for these samples equaled 318 mg/kg.
- Smelter Plateau (NR12): 30 percent of the 136 samples exceeded the screening level. The average arsenic concentration for these samples equaled 1,266 mg/kg. As discussed in Section 7.2, the results varied between ash piles, tailings, and dross tested in NR12.
- Agua Fria Tailings Pile (NR10): 75 percent of the 13 samples exceeded the screening level. The average arsenic concentration for these samples equaled 3,202 mg/kg.

Other non-residential exposure areas contained isolated areas with elevated arsenic concentrations, but the areas listed above had the most widespread distribution of arsenic-impacted soils with the greatest frequency of high arsenic concentrations. See Section 7.2 for details regarding all non-residential exposure areas.

The data, and the history of site operations (see Section 2), indicate that the tailings within the MTP are a source of arsenic, and that arsenic could potentially be transported off the Iron King Mine property via the transport mechanisms discussed in Section 8.

7.1.1.2 Lead

Figure 7-2 shows the sitewide distribution of lead in shallow soil, including both pre-RI and RI-collected data. The figure shows that the highest lead concentrations in surface soils were found at the greatest frequency in the area of, and adjacent to, the former Iron King Mine. Elevated lead concentrations were found in samples downgradient from this area within all segments of Chaparral Gulch, and the Tailings Floodplain. Elevated lead concentrations also were found in the former Pyrometallurgical Operations area and the Smelter Plateau, at lower concentrations and frequency.

The average lead concentration for 2,206 samples collected in the non-residential (NR) exposure areas equaled 643 mg/kg. Approximately 73 percent of the samples exceeded background for lead (34.8 mg/kg) and 30 percent exceeded the screening level (400 mg/kg). Of the 652 samples that exceeded the screening level, the average lead concentration equaled 2,250 mg/kg. Lead concentrations exceeded 1,000 mg/kg in 14 exposure areas, and exceeded 10,000 mg/kg in nine exposure areas. Section 7.2 provides a detailed description of the lead concentrations and distribution within each exposure area.

Exposure areas with the highest lead concentrations and the highest percentage of samples that exceeded the lead screening level are listed below.

Former Iron King Mine MTP and MTP Blow Out Path

- MTP (NR17): all tailings samples exceeded the screening level. The average lead concentration for these 79 samples equaled 3,449 mg/kg.
- Former Mineworks Area (NR16): 53 percent of the 104 samples exceeded the screening level. The average lead concentration for these samples equaled 5,134 mg/kg.
- JT Septic Facility (NR4): 63 percent of the 9 samples exceeded the screening level. The average lead concentration for these samples equaled 1,954 mg/kg.
- MTP 1964 Blow Out Path (NR5): 36 percent of the 63 samples exceeded the screening level. The average arsenic concentration for these samples equaled 2,456 mg/kg.

Chaparral Gulch Downgradient from NR5

- Middle Chaparral Gulch (NR6): 32 percent of the 168 samples exceeded the screening level. The average lead concentration for these samples equaled 1,297 mg/kg.
- Smelter Tailings Swale (NR7): 12 percent of the 85 samples exceeded the screening level. The average lead concentration for these samples equaled 595 mg/kg.
- Tailings Floodplain (NR8): 29 percent of the 355 samples exceeded the screening level. The average lead concentration for these samples equaled 2,267 mg/kg.

Humboldt Smelter and Smelter Plateau

- Former Pyrometallurgical Operations Area (NR11): 53 percent of the 319 samples exceeded the screening level. The average lead concentration for these samples equaled 1,409 mg/kg.
- Smelter Plateau (NR12): 38 percent of the 136 samples exceeded the screening level. The average lead concentration for these samples equaled 1,668 mg/kg.
- Agua Fria Tailings Pile (NR10): 75 percent of the 13 samples exceeded the screening level. The average lead concentration for these samples equaled 5,556 mg/kg.

Other non-residential exposure areas contained isolated areas with elevated arsenic concentrations, but these areas appear to have the most widespread distribution of source material. See Section 7.2 for details regarding all non-residential exposure areas.

7.1.1.3 Copper

Figure 7-3 shows the sitewide distribution of copper in shallow soil, including both pre-RI and RI-collected data. The figure shows that the highest copper concentrations in surface soils were found at the greatest frequency in the area of the former Humboldt Smelter. Very high copper concentrations also were found in samples downgradient from this area within the Smelter Tailings Swale. Elevated copper concentrations were also found in the area of the former Iron King Mine.

The average copper concentration for 2,110 samples collected in the non-residential (NR) exposure areas equaled 485 mg/kg. Approximately 18 percent of the samples exceeded background for copper (182 mg/kg) and only 4 percent exceeded the screening level (3,100 mg/kg).

Of the 80 samples that exceeded the screening level, the average copper concentration equaled 8,553 mg/kg. Copper concentrations exceeded 1,000 mg/kg in 14 non-residential exposure areas, and exceeded the screening level (3,100 mg/kg) in only four non-residential exposure areas, all adjacent to the former Humboldt Smelter area. Section 7.2 provides a detailed description of the copper concentrations and distribution for each exposure area.

Non-residential exposure areas that exceeded the copper screening level are all associated with the Humboldt Smelter or erosion from the smelter into downgradient areas, as listed below. All other non-residential areas did not have any samples that exceeded the copper screening level.

- Former Pyrometallurgical Operations Area (NR11). 19 percent of the 319 samples exceeded the screening level. The average copper concentration for these samples equaled 7,484 mg/kg. As discussed in Section 7.2, the results varied between ash piles, tailings, and dross tested in NR11.
- Smelter Plateau (NR12). Only 5 percent of the 136 samples exceeded the screening level. The average copper concentration for these samples equaled 9,650 mg/kg. As discussed in Section 7.2, the results varied between tailings and dross tested in NR12.
- Smelter Tailings Swale (NR7): 12 percent of the 86 samples exceeded the screening level. The average copper concentration for these samples equaled 13,644 mg/kg.
- Tailings Floodplain (NR8): Only 1 percent of the 355 samples exceeded the screening level. The average copper concentration for these samples equaled 8,733 mg/kg.

The distribution of copper concentrations that exceed background is generally limited to the Humboldt Smelter, the historical Humboldt Smelter Rail Spur through downtown Humboldt (potentially resulting from material spills from the railroad), the residential properties downwind of the Humboldt Smelter, and the Smelter Tailings Swale.

7.1.1.4 Zinc

Figure 7-4 shows the sitewide distribution of zinc in shallow soil, including both pre-RI and RI-collected data. The figure shows wide dispersion of zinc greater than background at 136 mg/kg throughout the non-residential and residential areas. Samples with zinc concentrations greater than 1,360 mg/kg were found in both the mineworks areas, and along rail routes.

The average zinc concentration for 2,200 samples collected in the non-residential (NR) exposure areas equaled 1,035 mg/kg. Approximately 79 percent of the samples from non-residential exposure areas exceeded background for zinc (136 mg/kg) but only eight samples, collected in four different exposure areas, exceeded the screening level of 23,000 mg/kg.

7.1.2 Sitewide Distribution of Shallow Sample Zn:Cu and Pb:Cu Ratios

Zinc to copper (Zn:Cu) and lead to copper (Pb:Cu) ratios were found to be indicators of contaminant source material at the Site. As detailed in Section 6.5 and Appendix I, soil impacted by operations from the Iron King Mine had lower concentrations of copper relative to lead and zinc, because ores from the mine contained high concentrations of lead and zinc, but contained low concentrations of copper. Conversely, soil impacted by operations from the Humboldt Smelter had higher concentrations of copper relative to lead and zinc, because the smelter processed ores that had high concentrations of copper and low concentrations of lead and zinc. Thus, soil impacted by operations from the Iron King Mine generally would be expected to have high Zn:Cu and Pb:Cu ratios, while soil impacted by operations from the Humboldt Smelter would be expected to have low Zn:Cu and Pb:Cu ratios.

Figure 7-5 provides sitewide plots of the Pb:Cu ratios while Figure 7-6 shows sitewide Zn:Cu ratios. Generally, both the Pb:Cu and Zn:Cu ratios are elevated (greater than 10) at the following locations:

- Entire Iron King Mine property including the MTP
- Tailings Floodplain and Smelter Plateau
- Within a small portion of the residential area located north of the former Humboldt Smelter

Ores from the Iron King Mine contained low concentrations of copper. Tailings from the MTP 1964 Blow Out at the Iron King Mine were transported along the Blow Out Path, along Chaparral Gulch, and into the Tailings Floodplain. The combination of elevated Pb:Cu and Zn:Cu ratios in the Tailings Floodplain supports this conclusion.

The distribution of high Zn:Cu and Pb:Cu ratios within Chaparral Gulch indicates that impacted materials within the gulch originated from the Iron King Mine property. For deposits within the upper and lower reaches of the gulch, and for reworked tailings within the gulch, Figure 7-5 shows that Pb:Cu ratios are uniformly higher than observed for samples from the Humboldt Smelter area or the Smelter Tailings Swale. Figure 7-6 shows that the Zn:Cu ratios are uniformly higher within the Iron King Mine property, the Middle Chaparral Gulch, and the Tailings Floodplain than samples from the Smelter tailings Swale. The data show that a significant portion of Iron King Mine tailings was likely transported within the gulch during and subsequent to the MTP Blow Out event in 1964, and also by direct discharge from the mine site, as discussed in Section 8.2.1.

One potentially complicating factor in this analysis is the preferential volatilization of lead from the smelter furnaces. As discussed in Section 8, lead impurities in the ores processed at the Humboldt Smelter would tend to be volatilized when heated to the temperatures attained in the furnaces, and subsequently transported offsite via air dispersion. This transport mechanism could cause high Pb:Cu ratios in surface soil samples (within a few inches of ground surface) even if Iron King Mine tailings are not present. Additionally, the dispersion of zinc dross throughout the APSI appears to have led to (1) a significant number of shallow soil samples with zinc concentrations above background, and (2) a number of samples (especially within the former Pyrometallurgical Operations area and the Smelter Plateau) having a high Zn:Cu ratio. These processes may have affected the Pb:Cu and Zn:Cu ratios that had not been highly disturbed by erosion, mass transport, or direct placement of materials.

7.1.3 Sitewide Distribution of Shallow to Deep Sample Metals Concentration Ratios

As discussed in Appendix E, soils near the mine and smelter that were impacted solely by windblown dust and stack emissions would be expected to have mine- and smelter-related contaminants at higher concentrations in surficial soils than in deeper soils. By contrast, natural soils that have not been impacted by windblown dust or stack emissions would not be expected to have shallow soil concentrations of chemical constituents significantly elevated compared to deeper soils. Areas impacted by erosion, transport of impacted materials in drainages, or direct placement of mine waste or other fill materials would have ratios dependent on the contaminant level of material transported and the sequence of deposition. Review of the shallow to deep ratios indicate the following:

- Figure 7-7 shows the shallow to deep soil concentration ratios for arsenic. These data indicate a general trend of decreasing shallow to deep arsenic concentration ratios with distance from Highway 69 toward the northwest. Overall, the distribution pattern supports an aerial transport pathway from the Iron King Mine, with some outliers due to naturally occurring variations in topography or geology. In the area of the lower portion of the Middle Chaparral Gulch and the Tailings Floodplain, the ratios are typically less than one, indicating that subsurface soils are more highly contaminated. Within both the former Mineworks area and the former Pyrometallurgical Operations area, the ratios vary considerably, indicating higher-concentration material at the surface and at depth.
- Figure 7-8 shows the shallow to deep soil concentration ratios for lead. The general trends are the same as those observed for arsenic. More of the samples in the Middle Chaparral Gulch have higher lead concentrations at the surface than at depth, however the Middle Gulch has been highly impacted by surface water transport and deposition of both impacted material from the MTP and less impacted material from upper Chaparral Gulch over time.

- Figure 7-9 shows the shallow to deep soil concentration ratios for copper. The highest ratios are concentrated in the former Pyrometallurgical Operations area, with some at the MTP and the former Mineworks Area. The highest shallow to deep copper concentration ratios observed offsite were in the areas north and directly adjacent to the former Pyrometallurgical Operations area. These trends were likely altered by import of dross well after the smelting operations had concluded.
- Figure 7-10 shows the shallow to deep soil concentration ratios for zinc. The highest shallow to deep zinc concentration ratios were observed in areas to the north of, and directly adjacent to, the MTP. The general trend is similar to that observed for arsenic and lead, with the ratio decreasing in the northerly direction away from Iron King Mine. Decreases in the concentration ratio were noted for locations just north of each of the east-to-west-trending ridgelines that are located north of the former Iron King Mine. This is potentially caused by the ridgelines acting as a windbreak for windblown tailings.

7.1.4 Other Chemicals of Interest

Other COIs found sitewide include manganese, iron, thallium, and antimony. These metals are identified as COIs in Section 6 (see Table 6-7) and are discussed in the HHRA in Section 9.

Residential properties 1907, 1910, and 1911 contain several shallow soil sample locations that had manganese and iron detections at least an order of magnitude above the manganese and iron screening levels. These three properties are located east of the Agua Fria River at the easternmost extent of the APSI. Generally, for locations east of the Agua Fria River, multiple samples exceeded screening levels for manganese, and multiple samples exceeded background levels for iron. For locations west of the Agua Fria River, however, the majority of shallow soil samples had manganese concentrations below screening levels, and iron concentrations below background. This distribution of concentrations suggests that the elevated levels of manganese and iron east of the Agua Fria River do not originate from mine- or smelter-related sources and are more likely related to differing geology east of the Agua Fria River. Similarly, elevated levels of manganese at other locations west of the Agua Fria River do not appear to be from mine- or smelter-related sources.

Thallium was detected in several shallow soil samples at the MTP. Sporadic detections of thallium above background were observed throughout the Site; however, the vast majority of shallow soil samples collected at the Site did not contain detectable levels of thallium, and even fewer samples contained thallium concentrations above background. Similar to manganese and iron, this distribution of concentrations suggests that the elevated levels of thallium do not originate from mine- or smelter-related sources.

The highest detection of antimony in shallow soil at the Site also was in a sample collected at the MTP. Shallow soil samples containing levels of antimony an order of magnitude above the screening level were detected in Properties 120 and 116. Roughly half of the shallow samples collected at the Site did not contain detectable levels of antimony, and even fewer samples contained antimony concentrations above background (similar to thallium as discussed in the preceding paragraph). Similar to thallium, this distribution of concentrations suggests that the elevated levels of antimony do not originate from mine- or smelter-related sources.

7.2 Soil: Former Iron King Mine Property, Former Humboldt Smelter Property, and Other Non-Residential Areas

This section summarizes the nature and extent of contamination in surface soil and subsurface soil in source areas and other non-residential areas. The discussion does not refer to sampling or test results for residential-only areas, which is discussed in Section 7.3. Identification of COIs and the estimate of respective background and screening level concentrations were detailed in Section 6. Section 9.6.3

provides a discussion of the provisional lead screening level. The arsenic screening level incorporates site-specific bioavailability (Section 9.4.5 and Appendix H) and corresponds to a 1 x 10^{-4} excess lifetime cancer risk (ELCR).

The COIs discussed in this section are compared with the the following background and screening levels:

Chemical of Interest	Background Level	Screening Level
Arsenic	112 mg/kg	194 mg/kg
Lead	34.8 mg/kg	400 mg/kg
Copper	182 mg/kg	3,100 mg/kg
Zinc	136 mg/kg	23,000 mg/kg

Table 7-3 provides the results from geotechnical laboratory testing performed on samples from the MTP and material from other areas of the Site. Tables 7-4 through 7-10 include summaries of analytical results for soil samples collected in each exposure area discussed in this section, for arsenic, lead, other metals, and the other analytical groups listed in Section 6.4.1. Figures prepared for this section present surface and subsurface soil concentrations separately. Surface soil samples have a beginning depth less than or equal to 2 feet bgs; subsurface soil samples have beginning depth greater than 2 feet bgs. At locations where multiple surface (or subsurface) samples were collected, the concentration shown on the figure represents the maximum result.

7.2.1 Former Iron King Mine Property: Operation and Source Areas

The former Iron King Mine property occupies about 150 acres on the west side of State Highway 69. Mining was performed from the late 1890s to 1968, with production peaking in 1963 (ACS, 2008). Ore was milled and concentrated onsite. Lead and zinc concentrates were shipped offsite by rail for smelting and metal recovery. Mill waste (tailings) was stockpiled onsite. A large portion of the property is now covered with tailings and waste rock piles. Section 2 provides a detailed description of the development and history of the Iron King Mine.

NAI currently owns the eastern portion of the property and produces fertilizers and soil supplements. Several stormwater retention ponds are used to control surface water flow around the stockpiled tailings and the NAI Operations area. A residential area is located northeast of the NAI Operations area.

Exposure areas on, and adjacent to, the former Iron King Mine property are shown on Figure 6-3 and include the following:

- **NR14 South of Former Iron King Mine Property.** This area includes the Galena Gulch drainage, which drained the former Mineworks area and waste rock piles located along the northern bank of Galena Gulch (Figure 2-1).
- **NR15 Auto Yard.** Drainage conveyed discharges from impoundments located at the MTP and former Mineworks area through NR15. This area is also within the drainage path of the MTP 1964 Blow Out.
- **NR16 Former Mineworks Area.** This area includes mine headworks, shafts, ore processing, and numerous buildings (see Figure 2-1). It also included ore processing to obtain lead and zinc concentrates, and cyanide leaching of gold. This area operated prior to 1940 through 1970, with maximum periods of operation during World War II. It includes the former fertilizer plant.
- **NR17 Main Tailings Pile.** This area is the site of smaller impoundments during early mine operations that received discharges from processing areas in NR16. It now occupies about 52 acres, is up to 100 feet high, and contains over 3.5 million yd^3 of arsenic- and lead-laden tailings.
- **NR18 NAI Operations Area.** This area is currently operational.

- **NR19 Former Glory Hole and North of Main Tailings Pile.** The Glory Hole resulted from the collapse of all levels of at the north end of the mine. It has been used as a landfill for municipal waste, construction debris, and tires. It also included the slurry line to the former Small Tailings Pile (located in NR20).
- **NR20 North of Chaparral Gulch.** This area is in the drainage pathway from mining operations, and is the location of the former Small Tailings Pile produced by cyanidation of the mill tailings for gold and silver recovery.

Sections 7.2.1.1 through 7.2.1.4 below provide a more detailed description of the exposure areas within the former Iron King Mine property in order of most impacted to least (NR17, NR16, NR19, and NR18). Descriptions of the areas adjacent to the former Iron King Mine property (NR14, NR15, NR20) are presented in Section 7.2.4.

The primary wastes/source materials in these areas are tailings and waste rock. A summary of the surface analytical results from the former Iron King Mine property operations and source areas is provided in Table 7-4. Subsurface analytical results are provided in Table 7-8.

7.2.1.1 NR17 Main Tailings Pile

Historical aerial photographs, provided in Appendix C, show that the MTP was developed as a series of smaller impoundments within shallow drainages that were tributaries to Chaparral Gulch. By the 1940s, three piles were located within the northwest corner of the existing footprint. By the 1950s, two large piles were evident, and by early 1964, the tailings encompassed an area similar in size to the upper MTP. Since the blow out and formation of the lower MTP in 1964, minor reworking and regrading has taken place, resulting in the current MTP footprint, which occupies a surface area of about 55 acres (see Figure 7-11).

CPT (GEI, 2012) was used to estimate the approximate interface with the natural ground surface, and the corresponding thickness of tailings, based on the assumption that the tailings would be considerably weaker than the underlying natural material. While the depth of the tailings appeared to correlate well with the underlying natural topography indicated by historical aerial photographs, GEI noted that uncertainty exists with respect to the contact location between tailings and natural soil, and potential variation within the drainages. Based on observation of the soils located adjacent to the MTP, the natural soils were identified as the upper member of the Hickey Formation, which includes unconsolidated, poorly sorted silt, clay, sand, and gravel (see Section 5.4.2).

Two of the cross sections developed as part of this work are depicted on Figures 7-12 through 7-14. The estimated thickness of the upper MTP ranges from about 8 to 105 feet below existing grade, with the thinnest tailings present on the southwest area of the pile. The estimated thickness of the lower MTP ranges from 3 to 60 feet, with the thinnest section on the west side of the pile. The southeastern slope of the upper MTP is approximately 100 feet high and steep, with a grade of approximately 2:1 (H:V), where the “MTP Blow Out” slope failure occurred.

The volume of tailings at the MTP equaled approximately 3.5 million yd^3. The methodology for estimating the volume of tailings is described in Section 7.2.5.

Photographs 2 through 8 in Appendix A show the MTP.

Geotechnical Characteristics. The surface of the MTP is oxidized and appears yellow to orange. In all 12 soil borings where the color was noted in the boring log, the tailings transition to a gray or dark gray/green color between 0.5 foot and 4 feet of the ground surface, indicating reducing (absence of oxygen) conditions. The tailings were classified predominantly as silt (ML) or silty sand (SM), as defined by the Unified Soil Classification System (ASTM D2487). The average fine (0.075 millimeter [mm]) content ranges from 40 to 99.6 percent, averaging 72 percent. The remainder consists of sand. At the bottom of the MTP, the Hickey Formation materials also contained up to 19.3 percent gravel. The tailings at borehole MTP-SB01 in the lower MTP had greater than 50 percent fine sand, whereas the tailings at boreholes MTP-SB02 and MTP-SB03 in the upper MTP ranged from 1 to 39 percent fine sand.

The silt is generally non-plastic, but toward the bottom of the MTP it has a plasticity index up to a maximum of 5 percent. Being non-plastic, the tailings are likely to behave as cohesionless material when wet, but appear to have a high dry strength. The high dry strength is evident around the head scarp of the old slide failure in the upper MTP, where slopes are standing as steep as 75 degrees to a height of up to 20 feet. Shear strength testing indicated that the friction angle varies from 30 to 39 degrees.

Geotechnical soil test results are summarized in Table 7-3.

Moisture Content. The moisture content and calculated percent saturation for samples collected from borings within the MTP are presented in Table 7-2. Percent saturation is calculated based on the dry density, moisture content, and estimated specific gravity. The estimated percent saturation is subject to some error because of the uncertainty with respect to accurately estimating moisture, density, and specific gravity. Examination of these data shows that the moisture content does not vary as either a function of depth or location within the pile (upper or lower MTP). The moisture content ranged from 2.1 percent to a maximum of 34.9 percent, averaging 16.7 percent. For those samples in which dry density was also reported, the calculated percent saturation ranged from 12 to 98 percent. Three of the eight samples with saturation values over 89 percent were located at the base of the MTP within the Hickey Formation. The other five high-saturation samples were located between 19 and 45 feet bgs. These results indicate that the tailings are not saturated, but may have isolated zones with higher moisture content.

Monitoring well data confirm observations pertaining to soil moisture and saturation. Table 5-5 presents the water level measurement data for monitoring wells, while Table 5-4 shows the screen interval and hydrogeologic unit for each well. Table 5-5 shows that all wells screened in the tailings (MTP-MW1, MTP-MW2, MTP-MW3, MW-08S, and MW-09S) were dry during the most recent monitoring events in 2014. During previous monitoring events, the groundwater elevation in MW-09S and MW-08S was near the bottom of the tailings. For example, the groundwater elevation at MW-09S was measured as 4,680 feet msl, while the bottom of the tailings in the cross section shown on Figure 7-12 is approximately 4,675 feet msl at MW-09D.

Hydraulic Conductivity. Hydraulic conductivity ("K" values) testing conducted on 12 tailings samples, listed in Table 7-2, indicated high variability in tailings hydraulic conductivity with laboratory measurements ranging from 5.00 x 10^{-}3 centimeters per second (cm/sec) to 2.06 x 10^{-6} cm/sec. The average for the 12 laboratory results equaled 4.92 x 10^{-6} cm/sec. Five of the 12 samples had K values less than 9.55 x 10^{-6} cm/sec. There does not appear to be any apparent correlation between location within the piles or material types and hydraulic conductivity.

Arsenic in MTP Tailings

The average arsenic concentration for 38 shallow (surface to 1 foot bgs) surface samples collected on both the upper and lower MTP equaled 3,768 mg/kg. Arsenic concentrations for the upper and lower MTP were similar, averaging 3,832 mg/kg and 3,644 mg/kg, respectively. The maximum arsenic concentration for all surface samples equaled 12,000 mg/kg, recorded at location OS-12 on the upper MTP, just south of the blow out scarp (see Figure 7-15). The next largest arsenic concentration for all MTP surface samples, equal to 7,600 mg/kg, was recorded for location IK-S4 on the lower MTP. Nearly 80 percent of the samples had arsenic concentrations greater than 2,000 mg/kg, exceeding both the background (112 mg/kg) and screening (194 mg/kg) levels by a significant margin.

The average arsenic concentration for 41 below-surface tailings samples (all samples obtained 4 feet or more bgs) equaled 4,145 mg/kg. The average below-surface concentration of 4,942 mg/kg at the lower MTP exceeded the average of the upper MTP (3,818 mg/kg). The maximum below-surface arsenic concentration equaled 13,000 mg/kg, and was obtained 4.5 feet bgs at soil boring B-3 located on the lower MTP (see Figure 7-16). Of the 41 tailings samples, 40 had arsenic concentrations greater than 2,000 mg/kg. All below-surface MTP tailing sample results exceeded both the background and screening levels for arsenic.

Four borings penetrated below the tailings into the underlying Hickey formation (boring MTP-SB01 in the lower MTP; borings B-5, MTP-SB-02, and MTP-SB-03 in the upper MTP). The results of all samples tested in the Hickey Formation material (ranging from 22 to 45.1 mg/kg) were less than the background level for arsenic (see Figure 7-16 for locations).

Test results for surface samples collected at the edge of the tailings were highly variable, ranging from a low arsenic concentration of 22 mg/kg at IKM-HA105 compared to 6,400 mg/kg at S25, both at the lower MTP. The maximum surface concentration at the edge of the tailings equaled 6,460 mg/kg at IK-S1, located on the upper MTP. For all subsurface samples obtained from the four soil boring locations at the edge the MTP, arsenic concentrations decreased to below 55 mg/kg, indicating samples were likely obtained in the natural ground, and that the natural ground had not been contaminated.

Arsenic in NR17 adjacent to the MTP Tailings

Twenty-four surface samples were tested for arsenic in the NR17 area adjacent to the tailings piles on the southwest, southeast, and east sides of the MTP. Four of the samples yielded tests results for arsenic between 180 and 290 mg/kg. For all other locations, arsenic concentrations ranged from 19 to 71 mg/kg, with an average concentration equal to 39 mg/kg, all below the background (112 mg/kg) and the screening levels (194 mg/kg).

Lead in MTP Tailings

The distribution of lead concentrations for the tailings surface samples was similar to that found for arsenic. The average lead concentration from the lower MTP (2,193 mg/kg) was less than the average lead concentration for the upper MTP (2,856 mg/kg). The maximum lead concentration at the surface in the lower MTP equaled 3,500 mg/kg at IK-S4, while the maximum lead concentration at the surface in the upper MTP equaled 7,500 mg/kg at S19. See Figure 17 for surface sample locations and lead concentrations.

More than 80 percent of the surface samples had lead concentrations greater than 1,300 mg/kg, exceeding both the background (34.8 mg/kg) and screening (400 mg/kg) levels. Test results are summarized in Table 7-4.

The average lead concentration for 40 below-surface tailings samples (all samples obtained 4 feet or more bgs) equaled 3,713 mg/kg. (Note that the B-2 result of 24,000 mg/kg appears to be an outlier and is not included in the calculation.) The average below-surface lead concentration of 3,189 mg/kg at the lower MTP was less than the average concentration for the upper MTP (3,965 mg/kg). The maximum below-surface lead concentration equaled 8,230 mg/kg, obtained 35 feet bgs at soil boring IKJ-527 on the upper MTP. See Figure 7-18 for subsurface sample locations and lead concentrations. Almost 80 percent of the below-surface tailings samples had lead concentrations greater than 2,600 mg/kg, exceeding both background (34.8 mg/kg) and screening (400 mg/kg) levels by a significant margin.

Four borings penetrated below the tailings into the underlying Hickey formation (boring MTP-SB01 in the lower MTP; borings B-5, MTP-SB-02, and MTP-SB-03 in the upper MTP). For these four locations, lead concentrations ranged from 11 to 73.5 mg/kg. Lead concentrations for three of the samples were below background (34.8 mg/kg), while the fourth was below the screening level of 400 mg/kg.

Lead concentrations for surface samples collected at the edge of the tailings were highly variable, similar to the large variation observed for arsenic, ranging from a low of 16.5 mg/kg at IKM-HA105 compared to a high of 5,910 mg/kg at IK-S1. Sample locations are shown on Figure 7-17. For all subsurface samples obtained from the four soil borings at the edge of the tailings, lead concentrations were less than 37 mg/kg, with six of the seven samples reporting concentrations less than the background of

34.8 mg/kg. Subsurface lead sample locations and concentrations are shown on Figure 7-18. As with the observation pertaining to arsenic, these results indicate that the subsurface samples at the edge of tailings were likely obtained in natural ground, and that the natural ground had not been contaminated.

Lead in NR17 adjacent to the MTP Tailings

Twenty-four surface samples were tested for lead in the NR17 area adjacent to the MTP on the southwest, southeast, and east sides of the MTP. Samples locations and lead concentration data are shown on Figure 7-17. None of these samples exceeded the screening level of 400 mg/kg; just over 50 percent were below the background (34.8 mg/kg). All 35 subsurface samples (sample locations and lead concentrations are shown on Figure 7-18) had lead concentrations less than background, with about 50 percent less than 20 mg/kg.

MTP Other COIs

Zinc concentrations in the upper and lower MTP tailings ranged from 1,520 mg/kg (surface sample at IKJ-530) to 75,000 mg/kg (B-2 at a depth of 14.5 feet bgs). Fifty percent of the combined surface and subsurface samples had concentrations exceeding 10,000 mg/kg. All zinc concentrations exceeded the background level for zinc of 136 mg/kg, while only four samples exceeded the screening level of 23,000 mg/kg.

Copper concentrations in the upper and lower MTP tailings ranged from a low of 6.8 mg/kg to a high of 1,500 mg/kg. Ten percent of the samples had concentrations less than background (182 mg/kg), while all results were less than the screening level (3,100 mg/kg).

For surface soil samples, 15 samples exceeded the screening level for antimony (31 mg/kg) with a maximum concentration equal to 143 mg/kg; one sample exceeded the screening level for hexavalent chromium (0.3 mg/kg) with a concentration equal to 1.4 mg/kg; one sample exceeded the screening level for cobalt (23 mg/kg) with a concentration equal to 29.5 mg/kg; six samples exceeded the screening level for mercury (23 mg/kg) with a maximum concentration equal to 65 mg/kg; and six samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 15.4 mg/kg. See Table 7-4 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for surface soils.

For subsurface soil samples, 24 samples exceeded the screening level for antimony (31 mg/kg) with a maximum concentration equal to 360 mg/kg; four samples exceeded the screening level for cadmium (70 mg/kg) with a maximum concentration equal to 210 mg/kg; three samples exceeded the screening level for cyanide (21 mg/kg) with a maximum concentration equal to 172 mg/kg; 12 samples exceeded the screening level for mercury (23 mg/kg) with a maximum concentration equal to 160 mg/kg; and nine samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 3.2 mg/kg. See Table 7-8 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for subsurface soils.

Zinc and Copper in NR17 adjacent to MTP Tailings

Seventeen surface samples were tested for zinc in the NR17 area adjacent to the tailings piles on the southwest, southeast, and east sides of the MTP. Zinc concentrations ranged from 50.6 to 492 mg/kg, all less than the screening level of 23,000 mg/kg. Fifty percent of the samples had zinc concentration less than background (136 mg/kg). For 35 subsurface samples, zinc concentrations ranged from 42 to 123 mg/kg, all less than background.

Seventeen surface samples were tested for copper in the NR17 area adjacent to the tailings piles on the southwest, southeast, and east sides of the MTP. Copper concentrations ranged from 26.1 to 69 mg/kg, all less than the background level of 182 mg/kg. For 35 subsurface samples, copper concentrations ranged from 25.7 to 68.3 mg/kg, all less than background.

7.2.1.2 NR16 Former Mineworks Area

The former Mineworks area (NR16) was the site of mine headworks, shafts, ore processing facilities, impoundments, and numerous mine buildings. Ore processing facilities operated from prior to 1940 through 1970. The exposure area also includes the former Fertilizer Plant area (see Figure 2-1). More information on the former Mineworks area is presented in Section 2.1.2. Figure 6-3 shows the location of NR16 relative to other exposure areas.

Waste rock associated with former mining operations is present over a large portion of the former Mineworks area as a veneer and in piles. Currently, the former Fertilizer Plant area is mostly covered by waste rock surface deposits and tailings, as well as abandoned buildings, pads, sumps, tanks, and an ore bin.

Arsenic and Lead in Soil

Over 100 surface and subsurface soil samples were collected and tested for lead and arsenic in NR16. About 40 percent of the samples had arsenic concentrations less than the screening level (194 mg/kg) and 26 percent less than the background level (112 mg/kg). The average arsenic concentration for all samples equaled 634 mg/kg. Eighteen percent of surface and subsurface samples had arsenic concentrations between 1,000 and 5,060 mg/kg.

The highest arsenic concentrations were found on the eastern portion of NR16 within the area of the former milling operations facilities and extending to the south into the former Fertilizer Plant area. Sample locations and arsenic concentrations for surface soils are shown on Figure 7-15. The maximum arsenic concentration (5,060 mg/kg) was found at IKV-121, located just west of the MTP, at a depth of 4 feet. Only two other subsurface samples exceeded 1,000 mg/kg: IKV-119 at 1,520 mg/kg, and IKJ-502 at 1,020 mg/kg. Fifty percent of the subsurface samples had arsenic concentrations less than background (112 mg/kg).

Only 20 percent of the surface samples had concentrations less than background (112 mg/kg), and fewer than 40 percent of the surface samples had concentrations less than the screening level (194 mg/kg). The average arsenic concentration for surface soils equaled 655 mg/kg. Eighteen percent of the samples had arsenic concentrations greater than 1,000 mg/kg. Figure 7-15 provides a good indicator of the distribution of arsenic concentrations in surface soils within NR16.

Lead concentrations in NR16 were much higher relative to screening and background levels than concentrations observed for arsenic. Sample locations and lead concentrations for surface soils are shown on Figure 7-16. Of the 104 surface and subsurface samples, 53 percent had lead concentrations greater than the screening level (400 mg/kg); about 15 percent were less than background (34.8 mg/kg). The average lead concentration for surface and subsurface samples equaled 2,787 mg/kg.

Average lead concentrations in surface soils were greater than those recorded for subsurface soils by a factor of three: 3,147 mg/kg compared to 1,068 mg/kg. Nine surface samples had lead concentrations exceeding 10,000 mg/kg, with a maximum lead concentration of 65,700 mg/kg at IKM-HA088, located just west of the MTP.

Other COIs in Soil

For surface soil samples, seven samples exceeded the screening level for antimony (31 mg/kg) with a maximum concentration equal to 125 mg/kg; six samples exceeded the screening level for cobalt (23 mg/kg) with a maximum concentration equal to 35.1 mg/kg; one sample exceeded the screening level for manganese (1,800 mg/kg) with a maximum concentration equal to 7,880 mg/kg; four samples exceeded the screening level for mercury (23 mg/kg) with a maximum concentration equal to 63.9 mg/kg; and 20 samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 4.4 mg/kg. See Table 7-4 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for surface soils.

For subsurface soil samples, two samples exceeded the screening level for antimony (31 mg/kg) with a maximum concentration equal to 83.7 mg/kg; one sample exceeded the screening level for cadmium (70 mg/kg) with a concentration equal to 106 mg/kg; four samples exceeded the screening level for cobalt (23 mg/kg) with a maximum concentration equal to 51.7 mg/kg; one sample exceeded the screening level for cyanide (21 mg/kg) with a maximum concentration equal to 26.5 mg/kg; and 12 samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 4.2 mg/kg. See Table 7-8 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for subsurface soils.

7.2.1.3 NR19 Former Glory Hole and North of Main Tailings Pile

NR19 extends north of the former Mineworks area (NR16), upper MTP (NR17), and the NAI Operations area (NR18) to Chaparral Gulch (see Figure 6-3). Features within NR19 include the former Glory Hole, (collapsed mine workings), waste rock piles north of the former Glory Hole, and a former Small Tailings Pile, which was excavated and consolidated at the MTP in 2011. The area includes the location of two former piles of rusted drums associated with the cyanide leach operations (see Section 3.2.1.2), removed between 1998 and 2001 by the operator; and the alignment of the slurry line that conveyed slurry to the former Small Tailings Pile during gold processing operations.

Current zoning for this area is light industrial use (Figure 5-16B). Upon cleanup, this area could be rezoned and developed for residential use.

Housing is located to the north, just over the ridge in similar terrain. The former Iron King Mine property north of Chaparral Gulch does not appear to have been used directly in mining operations (though soils in that area do have arsenic and lead concentrations elevated significantly above background and screening levels). Residential housing areas are located west of NR20 and west of Highway 69.

Arsenic and Lead in Soil

Over 200 surface samples were tested for arsenic and lead in area NR19. See Figures 7-15 and 7-16 for the sample locations and the distribution of arsenic concentrations in surface and subsurface soils. Table 7-4 provides a summary of concentration data. The maximum arsenic concentration (1,980 mg/kg) was found at IKJ-578, located in the area of the former Small Tailings Pile, removed in 2011. Of the seven samples that exceeded 1,000 mg/kg, five were from the former Small Tailings Pile. Note that the data from the Small Tailings Pile, included in the dataset, predates removal of the pile.

Not including samples from the former Small Tailings Pile, 72 percent of samples from NR19 had arsenic concentrations below the screening level (194 mg/kg) and 61 percent were below background (112 mg/kg). About 10 percent of the samples had arsenic concentrations exceeding 500 mg/kg. The maximum arsenic concentration (1,730 mg/kg) was found at IKM-HA016, which appears to be associated with drainage from the former Glory Hole to Chaparral Gulch, based on a 1953 aerial photograph (and other later photographs) provided in Appendix C. Several other samples along this drainage (IKM-HA148, IKM-HA 149, and IKM HA150) also had elevated arsenic concentrations, ranging from 498 to 800 mg/kg. Elevated arsenic concentrations were found in the area just north of the MTP at IKM-HA001 (1,170 mg/kg), IKM-HA005 (954 mg/kg), and BIO-09 (816 mg/kg), and in the area of former mine shafts and waste piles HA 136 (714 mg/kg) and HA 131 (680 mg/kg). Only two samples taken at the location of the former Glory Hole were above the screening level (IKV-133 at 78.4 mg/kg and IK-S23 at 195 mg/kg); the remaining samples were below background.

Seventy-eight percent of the 47 subsurface samples had arsenic concentrations less than background (112 mg/kg) and 85 percent were less than the screening level (194 mg/kg). Of the remaining seven subsurface samples, only two had arsenic concentrations greater than 500 mg/kg. IKJ-508, located just south of the former Glory Hole, had a concentration of 797 mg/kg at 10.4 feet. IKM-HA010, located along the former slurry line, had a concentration of 547 mg/kg at 2.8 feet. See Figures 7-17 and 7-18 for the sample locations and the distribution of lead concentrations in surface and subsurface soils. Table 7-4 provides a summary of concentration data.

The lead distribution within NR19 was found to be similar to that for arsenic. About 12 percent (23 samples) of surface and subsurface samples had lead concentrations exceeding 400 mg/kg (not including samples from the removed former Small Tailings Pile). Similar to the arsenic distribution, elevated lead concentrations were found in the area of the former mine shafts and waste piles located southwest of Chaparral Gulch, along the former slurry line, and south of the former Glory Hole. Of the 23 samples with lead concentrations exceeding 500 mg/kg, 7 were surface samples and 3 were below the surface.

Lead concentrations of 4,270 and 3,050 mg/kg were recorded for surface samples at IKM-HA131 and IKM-HA-033 near the mine shafts and waste piles located southeast of Chaparral Gulch. Along the former slurry line, a lead concentration of 4,130 mg/kg was recorded at 2.83 feet bgs at IKM-HA010. South of the former Glory Hole, lead concentrations were reported at 2,140 mg/kg for a subsurface sample from 10.4 feet at IKJ-508, and 2,020 mg/kg for a surface sample from IKJ-503 (Figures 7-17 and 7-18; Tables 7-4 and 7-8).

Other COIs in Soil

For surface soil samples, three samples exceeded the screening level for cobalt (23 mg/kg) with a maximum concentration equal to 28 mg/kg; three samples exceeded the screening level for manganese (1,800 mg/kg) with a maximum concentration of 2,100 mg/kg; and 21 samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 3.1 mg/kg. One sample exceeded the screening level for benzyl butyl phthalate (280 mg/kg) with a concentration of 340 mg/kg. See Table 7-4 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for surface soils.

For subsurface soil samples, three samples exceeded the screening level for cobalt (23 mg/kg) with a maximum concentration equal to 35 mg/kg; 12 samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 3.8 mg/kg; one sample exceeded the screening level for benzo[a]pyrene (0.015 mg/kg) with a concentration of 0.11 mg/kg; one sample exceeded the screening level for Aroclor 1016 (4 mg/kg) with a concentration of 6.1 mg/kg; and one sample exceeded the screening level for dieldrin (280 mg/kg) with a concentration of 340 mg/kg. See Table 7-4 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for surface soils.

7.2.1.4 NR18 North American Industries Operations Area

The NAI Operations area (NR18) processes tailings from the MTP to produce a liquid fertilizer product called Hydromax. This area is also susceptible to impacts from windblown MTP tailings. Several stormwater retention ponds are currently in the area to control surface water flow around the MTP and the NAI Operations area. More information on fertilizer operations is presented in Sections 2.1.2.5 and 2.3.2.1.

Arsenic and Lead in Soil

Elevated concentrations of arsenic and lead were reported for surface soils at NR18 (Table 7-4 and Figure 7-15). Average subsurface concentrations for the five locations sampled equaled 29.2 mg/kg for arsenic and 15.2 mg/kg for lead, both less than the respective background concentrations of 112 mg/kg and 34.8 mg/kg.

For surface soils, 50 percent of the surface soils exceeded the arsenic screening level of 194 mg/kg, and 77 percent exceeded background (112 mg/kg). Twenty percent of the surface samples (eight samples) exceeded 500 mg/kg for arsenic with a maximum arsenic concentration of 3,090 mg/kg reported at IK-S27, located within the operations area.

Twenty-two percent of surface samples exceeded the lead screening level of 400 mg/kg, and 83 percent exceeded background (34.8 mg/kg). Sample locations and lead concentrations for surface soils are shown on Figure 7-17. The average lead concentration equaled 739 mg/kg for 37 surface samples. Seven surface samples had lead concentrations greater than 500 mg/kg. The maximum lead concentration for surface samples at NR18 was 16,693 mg/kg, and was reported for IK-S27.

Other COIs

For surface soil samples, one sample exceeded the screening level for antimony (31 mg/kg) with a concentration equal to 32.8 mg/kg; six samples exceeded the screening level for cobalt (23 mg/kg) with a maximum concentration equal to 59.3 mg/kg; one sample exceeded the screening level for mercury (23 mg/kg) with a concentration equal to 26 mg/kg; and two samples exceeded the screening level for thallium (0.78 mg/kg) with a maximum concentration equal to 2.9 mg/kg. See Table 7-4 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for surface soils.

None of the subsurface samples exceeded screening levels for other COIs at NR18. See Table 7-8 for details regarding number of samples, background concentration data, and test results for other analytes that did not exceed screening levels for subsurface soils.

7.2.2 Former Humboldt Smelter Property: Operation and Source Areas

Source areas at the former Humboldt Smelter property include the former Pyrometallurgical Operations area (NR11), the Smelter Plateau (NR12), the Smelter Tailings Swale (NR7), and the Agua Fria Tailings Pile (NR10). The Tailings Floodplain (NR8), which contains tailings mobilized from the Smelter Tailings Swale, is also a significant source area at the former Humboldt Smelter property, but is discussed in Section 7.2.3 in the overall context of the Chaparral Gulch drainage system.

Figures 7-19 and 7-20 show sample locations and arsenic concentrations for surface and subsurface soil for these exposure areas. Figure 7-21 shows sample locations and concentrations where dioxin/furan was found in surface soils. Figures 7-22 and 7-23 show sample locations and lead concentrations for surface and subsurface soils.

Table 7-5 provides a summary of COI and background screening level exceedances in surface soil/source material in these areas. Table 7-9 provides a summary of COI and background UTL exceedances in the subsurface soil/source material of these areas.

The primary source materials at the former Humboldt Smelter property are tailings, impacted soils, dross, and slag. Geotechnical soil test results for these materials at the former Humboldt Smelter property are provided in Table 7-3. The potential for these materials to leach metals and generate acidic conditions is discussed in Section 8.

7.2.2.1 NR11 Former Pyrometallurgical Operations Area

The former Pyrometallurgical Operations area (NR11) encompasses the portion of the former Humboldt Smelter property where the majority of the smelting operations occurred (see Section 2.3.3, and Figures 2-2 and 2-3). Ore concentrate was melted in furnaces, molten slag was separated from molten copper, and molten copper was then further refined to ingots in a series of converters. Dross is present as a thin layer and in piles and covers most of the exposure area (Figure 2-2). The dross consists of fine- to medium-grained sand, silt, and clay-sized material, as defined in the Unified Soil Classification System (ASTM D2488) (Table 7-3).

The native soil around and beneath the dross area consists of silty and clayey sand with gravel, based on subsurface exploration completed in 2008 (EA, 2008). The thickness of the dross was recorded as about 5 to 10 feet at the exploration locations, except at borehole ASH-SB04A/G9, where only 1 foot of dross material was observed. Slag deposits in this exposure area consist of black, brownish black, and bluish green glassy (amorphous) material. The slag appears to have been dumped as solidified blocks, portions that have been subsequently weathered to gravel or boulder-sized pieces. Other portions of the slag pile appear to have been placed while molten, forming sheets and flows, which later solidified. The slag deposits have formed a steep bluff overhanging the Agua Fria River. Slope failures have occurred, and slag extends down to the edge of the Agua Fria River in places. More information on the former Pyrometallurgical Operations area, slag piles, and dross is presented in Section 2.1.3. Historical photos of the area are provided in Appendix B (Cultural Resource and Historical Building Survey). Recent photographs of the former Humboldt Smelter, dross, and slag are provided in Photograph 1 and Photographs 26 through 34 in Appendix A.

Table 7-5 provides a summary of COI detections and exceedances above screening levels and background UTLs in surface soil. Table 7-9 provides a summary of COI detections and exceedances above screening levels and background UTLs in subsurface soil. Table 7-11 provides surface and subsurface results for this exposure area by material type (dross, Hickey conglomerate, native soil, slag, and tailings). For the majority of these samples, the material type was specified in the database that accompanied the ERT report. Samples of tailings, Hickey conglomerate, and native material were referred to as Non-Dross in the ERT report tables.

See Figures 7-19 and 7-20 for the sample locations and the distribution of arsenic concentrations in surface and subsurface soils. Figure 7-21 shows sample locations and concentrations of dioxin and furans found in surface soils at NR11. Figures 7-22 and 7-23 provides sample locations and lead concentrations in surface and subsurface soils. Table 7-4 provides a summary of concentration data.

Arsenic and Lead in Exposure Area NR11

There were 320 soil samples collected within NR11 during the four phases of the RI investigation. Samples were classified during and post-RI investigations as tailings, dross, ash pile, slag, Hickey Formation, and native. Some samples were not classified with any of these designations. The description below provides a comparison of the different material types chemical characteristics.

In general, elevated arsenic and lead concentrations are found primarily: (1) within the northern portion of NR11 in the area of the rail trestle, ore conveyors, and crushers; (2) in the upper middle portion of NR11 in the area of the former converters and smelters; and (3) at the perimeter to the northeast and west where waste products (tailings) were placed. See Appendix C (Cultural Resource and Historic Building Survey) for pictures and maps showing the layout of the facilities.

Review of sample location data indicates that material classified as ash piles, tailings, and dross are located throughout NR11. In many cases, material identified as dross is located adjacent to samples identified as tailings and ash piles. For instance, ASH-10 (dross) is located about 100 feet east of ASH-HAE11 (tailings) and 75 feet north of HIS-538 (ash pile). Both ash piles and tailings are present along the rail lines. The chemical signatures of the ash piles, the tailings, and the dross are much different. On average, the ash piles have over 10 times the copper as the tailings and about 4 times the copper as the dross. The ash pile material has just over twice the zinc contained in the tailings and about 30 percent more zinc than the dross. All of the materials are relatively low in arsenic, the dross is below background. The average lead concentration for the ash piles and tailings is about the same (about 1,200 mg/kg) and the average dross lead concentration is almost half at 621 mg/kg.

For all samples collected, the average concentrations for arsenic and lead equal 709 mg/kg and 1,409 mg/kg, respectively. Twenty-two percent of the samples exceeded the screening level for arsenic (194 mg/kg), while 53 percent of the samples exceed the screening level for lead (400 mg/kg).

For all samples, the average concentrations for copper and zinc equal 1,344 mg/kg and 1,375 mg/kg, respectively. Nineteen percent of the samples exceed the screening level for copper (3,100 mg/kg). None of the samples exceeded the screening level for zinc (23,000 mg/kg).

Arsenic and Lead in Dross

Samples categorized as dross contained low concentrations of arsenic. The average arsenic concentration equaled 61 mg/kg. Only 8 samples (out of 79) exceeded background (112 mg/kg). Only two samples exceeded the screening level (194 mg/kg): surface samples ASH-D12 (446 mg/kg) and ASH-L11 (215 mg/kg). None of the subsurface samples classified as dross exceeded background for arsenic.

Dross samples averaged 621 mg/kg lead. Eighty percent of the samples exceeded the lead screening level (400 mg/kg). For the dross samples that exceeded the screening level of 400 mg/kg, the average lead concentration equaled 705 mg/kg. Eight dross samples had lead concentrations exceeding 1,000 mg/kg; the maximum lead concentration in dross equaled 1,610 mg/kg at ASH-D12, located in the northeast corner of NR11 in the area of the former crushers. The rest of these eight samples were distributed at the surface throughout NR11 and were intermingled with ash piles and tailings.

Copper and Zinc in Dross

About 16 percent of the dross samples exceeded the screening level for copper (3,100 mg/kg). Of these samples, the average copper concentration equaled 6,348 mg/kg. Seventy-seven percent of the samples were below background (182 mg/kg).

The average zinc concentration for the 79 dross samples equaled 3,055 mg/kg. None of the samples exceeded the zinc screening level of 23,000 mg/kg. The maximum zinc concentration of 10,100 mg/kg was recorded for a surface sample at ASH-H11, located near the center of the exposure area between the rail lines.

Arsenic and Lead in Ash Piles

Seventy-one percent of the ash pile samples had arsenic concentrations less than background (112 mg/kg). The average arsenic concentration for all 50 samples equaled 225 mg/kg, which is above the screening level (194 mg/kg). The average concentration of the 12 samples that exceeded the screening level equaled 822 mg/kg, with concentrations between 1,030 and 2,290 mg/kg for 5 of those samples. None of the subsurface samples classified as dross exceed background for arsenic.

Ash pile samples averaged 1,186 mg/kg lead. Sixty-seven percent of the samples exceeded the lead screening level (400 mg/kg). For the ash pile samples that exceeded the screening level, the average lead concentration equaled 1,681 mg/kg. Eleven ash pile samples had lead concentrations exceeding 1,000 mg/kg; the maximum ash pile lead concentration equaled 11,400 mg/kg at HSJ-517, located at a depth of 4 feet near the center of NR11 between the rail lines.

Copper and Zinc in Ash Piles

About 65 percent of the dross samples exceeded the screening level for copper (3,100 mg/kg). Of these samples, the average copper concentration equaled 7,428 mg/kg. Only 8 percent of the samples were below background (182 mg/kg). Five samples had copper concentrations greater than 10,000 mg/kg, with a maximum of 21,300 mg/kg recorded at HSJ-517, located near the center of the exposure area between the former rail lines.

The average zinc concentration for the 50 ash pile samples equaled 4,152 mg/kg. None of the samples exceeded the zinc screening level of 23,000 mg/kg. The maximum zinc concentration (12,900 mg/kg) was recorded for a subsurface sample at HSJ-517, located near the center of the exposure area between the rail lines.

Slag

Photographs of the slag pile are provided in Appendix A (Photographs 29 through 34). Twelve slag samples were tested for arsenic, copper, lead, and zinc. Review of the data does not indicate consistency of COI concentrations between the slag samples. Two samples taken on different dates at HSJ-514 (in the center of the slag area) had considerably different results, with arsenic varying from 11.4 mg/kg to 551 mg/kg, and zinc varying from 449 mg/kg to 11,300 mg/kg. Overall, average arsenic and lead concentrations for 12 samples equaled 166 and 439 mg/kg, respectively. The average copper and lead concentrations equaled 4,070 and 3,761 mg/kg, respectively.

Other COIs in the Former Pyrometallurgical Operations Area

Dioxin/furan congeners were detected in 15 of the 17 samples analyzed, and exceeded the screening level (exposed as toxicity equivalents [TEQs]) in 13 of those samples (Table 7-5). Figure 7-21 shows the distribution of the dioxins/furans (as TEQs) in surface soil samples collected at the former Humboldt Smelter property, primarily in the dross area of the former Pyrometallurgical Operations area. The exceedances occur in areas where the dross is located. Based on studies that indicate negligible dioxin emissions from primary copper smelters (Secor International Inc., 1995a, 1995b), it may be that dioxins/furans were associated with processing of the dross material; however, there is no direct evidence that this is the case.

PCB congeners (Aroclor 1248 and Aroclor 1254) were detected in several samples at concentrations that exceed screening levels (Table 7-5). The samples were collected at two locations (HSJ-521 and HSJ-515) near a concrete aboveground storage tank support (EA, 2010); the PCB exceedances are likely associated with historical spills of PCB-containing materials such as waste oil.

PAH concentrations (benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, dibenzo[a,h]anthracene, and indeno[1,2,3-Cd]pyrene) exceeded screening levels at one location (HS-08).

Other COIs that exceeded screening levels included aluminum, antimony, cadmium (one surface sample), hexavalent chromium (one surface sample), cobalt, iron, manganese, silver (one surface sample), thallium, and PCBs. As shown in Tables 7-5 and 7-9, these metals occur at lower concentrations relative to their screening levels.

7.2.2.2 NR12 Smelter Plateau

The Smelter Plateau (NR12) is located south of the former Pyrometallurgical Operations area. Precursor mining operations, residential housing during smelting operations, and ancillary smelting and dross operations were present in this area. The Chaparral Gulch Shaft mine was located in the southeastern portion of the Smelter Plateau (see Figure 2-2); this mine provided ore to the Agua Fria Ore Mill and Smelter in the 1870s and 1880s. Residential housing, known as Nob Hill, was built in the early 1900s for smelter managers. Remains of tennis courts and home foundations are still present.

Development of the area is described and historical pictures are provided in Appendix B (Cultural Resource and Historic Building Survey) and in Appendix C (Aerial Photograph Analysis). Piles of dross are exposed on the plateau, a small slag pile is located along the eastern edge of the plateau upslope from the Agua Fria River, and a tailings pile is located in the former housing area. Soil borings indicate that a portion of the area is underlain by a thin layer of brown clay, 2 to 3 feet thick, which overlies the Hickey conglomerate geologic formation. The brown clay is a fat clay soil, and has high plasticity (Table 7-3).

Figures 7-19 and 7-20 show sample locations and the distribution of arsenic concentrations in surface and subsurface soils. Figures 7-22 and 7-23 provides sample locations and lead concentrations in surface and subsurface soils. Table 7-4 provides a summary of the concentration data.

Dross

The samples identified as dross within NR12 are located just south of NR11. As is the case with NR11, material identified as dross is located immediately adjacent to materials identified as tailings. The dross material within NR12 has similar COI concentrations as those found in NR11, with the exception of copper. The average arsenic concentration for 10 samples equaled 72 mg/kg, less than background. The three subsurface samples (less than 2 feet bgs) had arsenic concentrations less than background (112 mg/kg).

The average lead concentration equaled 493 mg/kg; all samples had lead concentrations above background (34.8 mg/kg), and five of the samples were above screening the level (400 mg/kg). The maximum lead concentration equaled 987 mg/kg at ASH-P4A, located at the ground surface. One subsurface sample (ASH-P14A) had a lead concentration that exceeded the screening level (400 mg/kg) at 471 mg/kg.

Nine of the 10 samples had copper concentrations less than background (182 mg/kg). One sample at ASH-PA14A had a copper concentration equal to 14,200 mg/kg.

The average zinc concentration for the 10 samples equaled 2,377 mg/kg. All samples exceeded background (136 mg/kg); none exceeded the screening level (23,000 mg/kg).

Tailings

The average COI concentrations for tailings within NR12 were similar to those recorded for tailings within NR11.

The average arsenic concentration for 48 samples equaled 484 mg/kg. Fifty-eight percent of the samples exceeded the screening level (194 mg/kg). For those samples that exceeded the screening level, the average arsenic concentration equaled 746 mg/kg. Four samples exceeded 1,000 mg/kg. The largest arsenic concentration in tailings equaled 7,470 mg/kg in a surface sample at ASH-HAM13, located near the former rail line at the northern end of NR12. Two other samples at this location, at 0.83 foot bgs and 1.83 feet bgs, had arsenic concentrations of 1,380 and 1,360 mg/kg, respectively.

The average lead concentration equaled 1,286 mg/kg for the 48 tailings samples. All samples except one exceeded background (34.8 mg/kg). For the 33 samples that exceeded the screening level, the average lead concentration equaled 1,821 mg/kg. A maximum lead concentration of 13,100 mg/kg was recorded for a surface sample at ASH-HA032 near a location identified as a building foundation in the 1940 aerial photograph interpretation provided in Appendix C. Several other very high lead concentrations were found nearby at the ground surface at ASH-HA023 (8,480 mg/kg) and ASH-HA023 (6,410 mg/kg). All lead samples were taken within 2 feet of the ground surface.

Copper concentrations were low for the tailings samples within NR12. Ninety percent of the samples had copper concentrations below background (182 mg/kg). Two samples had concentrations exceeding the screening level; 3,190 mg/kg at ASH-HAR08 and 2,940 mg/kg at ASH-HA029. Both of these samples were from the same building area identified above pertaining to maximum lead concentrations.

The average zinc concentration equaled 2,488 mg/kg for the 48 tailings samples. All but one of the samples exceeded background; none of the samples exceeded the screening level (23,000 mg/kg). The maximum zinc concentration equaled 15,300 mg/kg, recorded for a surface sample at ASH-032, the same location as the maximum lead concentration.

Slag

Five slag samples were tested from within the NR12 area. Similar to the results found for NR11, the COI concentrations varied considerably for surface samples.

One subsurface sample at 4 feet (HSV-109) reported concentrations below background for arsenic, copper, lead, and zinc. At the same location, concentrations ranged from below background for arsenic and copper, and above background but below the screening level for lead and zinc.

For the other three slag samples, arsenic concentrations ranged from 485 to 1,880 mg/kg; copper ranged from 2,010 to 2,880 mg/kg; lead ranged from 600 to 4,460 mg/kg; and zinc ranged from 1,100 to 31,600 mg/kg. The maximum concentrations were all found at SL-SS02 at the surface in the middle of the slag pile.

Native Samples

Within the NR12, 16 samples were identified as native. The samples are spread throughout NR12 and in many cases are located adjacent to materials identified as dross or tailings. For the native samples, the average arsenic concentration was below background at 84.7 mg/kg; the average lead concentration equaled 80.4 mg/kg (maximum was 158 mg/kg); the average copper concentration equaled 81.4 for 15 out of the 16 samples (one sample was at 2,090 mg/kg); and the average zinc concentration equaled 642 mg/kg. None of the samples exceeded the zinc screening level.

Other COIs

Other COIs that exceeded screening levels within the NR12 exposure area included aluminum, antimony (one surface sample), hexavalent chromium (one surface sample), cobalt, iron, and thallium (Tables 7-5 and 7-9). Dioxin/furan congeners were detected in one of three surface samples analyzed, and exceeded the screening level in that one sample; this sample was collected from HSJ-511 (Figure 7-21). The sample was collected adjacent to a small dross pile, and the exceedance appears to be associated with the dross material.

7.2.2.3 NR10 Agua Fria Tailings Pile

The Agua Fria Tailings Pile (NR10) is at the confluence of a small drainage above a steep near-vertical bank of silt, suggesting that a tailings dam(s) may have been located in this area at one time. It is no longer present. Sample locations and concentration data are presented on Figures 7-19 for arsenic and 7-22 for zinc. Photographs of the Agua Fria Tailings Pile are provided in Photographs 37 and 38 in Appendix A.

Arsenic

Thirteen surface and near-surface samples (less than 1 foot bgs) were tested from the NR10 area. Of the 13 samples, 12 were tested using XRF technology, and 1 was tested using laboratory analytical methods. Data reported for XRF have been correlated and adjusted with laboratory test data (see Section 6.1.2). Four of the samples had concentrations less than background (112 mg/kg) for arsenic. For the eight (out of 13) samples that exceeded the screening level, the average arsenic concentration equaled 3,202 mg/kg.

Lead

All samples exceeded the background level (34.8 mg/kg) for lead, while four samples had concentrations less than the screening level (400 mg/kg). For the nine (out of 13) samples that exceeded the screening level, the average lead concentration equaled 5,556 mg/kg. A maximum lead concentration of 11,500 mg/kg was recorded for the XRF sample XRF-524 at a depth of 0.91 foot.

Distribution is consistent across the exposure area with the lowest concentrations observed in samples collected at the west-southwestern perimeter, which is likely native soil. No subsurface samples were collected in this exposure area.

Other COIs

Ten of the 13 samples had copper concentrations greater than background (182 mg/kg). None of these samples were above the screening level for copper (3,100 mg/kg), averaging 1,083 mg/kg. These same samples all exceeded the background concentration for zinc (136 mg/kg). None of the samples exceeded the zinc screening level. Maximum zinc concentrations of 7,550 mg/kg and 4,460 mg/kg were recorded for two XRF samples located at XRF-524 (0.91 foot bgs) and XRF-522 (surface).

None of the samples exceeded background and screenings levels for other COIs at NR10.

7.2.2.4 NR7 Smelter Tailings Swale

The Smelter Tailings Swale is a bowl-like formation located topographically lower and west of the Smelter Plateau. Photographs 12 through 15 in Appendix A provide recent photographs of the Smelter Tailings Swale showing the deep erosional scars and efflorescent salts (Photograph 14).

The Smelter Tailings Swale, with an area of about 6 acres, was used to store or dispose of tailings produced as a waste product from concentrating ore to prepare copper concentrate to feed the smelter. As discussed in Section 2.1.3.6, the material was likely piped in as a slurry. Historical aerial photographs (see Appendix C) indicate the presence of several small dams and impoundments within the swale, all of which failed by 1940. The largest berm is visible across the bottom of the swale (Figure 2-2). Its failure has left a gully about 15 feet deep, visible in Photograph 14 in Appendix A.

The swale is underlain by the Hickey conglomerate geologic formation with local deposition of oxidized tailings overlying the HSCD. A schematic cross section (B-B') is provided on Figure 7-30. Remnant tailings within the swale are up to 12 feet thick upgradient of the failed berm (see Figure 7-32) and up to 8 feet thick upgradient of two locations identified through interpretation of historical aerial photographs as failed dams (see Appendix C). Figure 7-32 provides an isopach map showing the estimated distribution and thickness of the tailings, used to estimate the tailings volumes, discussed in Section 7.2.5.

Arsenic

Eighty-six surface and subsurface samples were collected and tested for arsenic and lead in NR7. Sample locations and arsenic concentrations are shown on Figure 7-19 for surface soils and Figure 7-20 for subsurface soils. Figure 7-22 shows the lead concentrations recorded for surface soils, and Figure 7-23 shows subsurface soil lead concentrations. Table 7-9 summarizes sample and concentration data.

About 76 percent of all samples had arsenic concentrations less than the screening level (194 mg/kg) and 60 percent were less than background (112 mg/kg). The average arsenic concentration for all samples within NR7 equaled 122 mg/kg. Only two samples had arsenic concentrations greater than 325 mg/kg: HS-01 at 1,100 mg/kg (located at the top of the swale near a location identified as a small impoundment based on historical aerial photograph interpretation), and at HSJ-503 at 708 mg/kg (located at the bottom of the swale near the berm shown on Figure 2-2). The remaining 18 NR7 samples (with concentrations above the screening level) had arsenic concentrations between 195 and 325 mg/kg.

Lead

Lead concentrations followed a similar pattern in NR7 as that found for arsenic. Eighty-eight percent of the samples had lead concentrations less than the screening level (400 mg/kg) and about 35 percent had lead concentrations less than background (34.8 mg/kg). Of the 10 samples that exceeded the screening level, only 2 samples, located at the bottom of the swale near the failed berm, exceeded 900 mg/kg:

HSJ-501 (surface sample) at 971 mg/kg, and XRF-611 (sample at 2.91 feet bgs) at 934 mg/kg. The remaining eight samples (all less than 1 foot bgs) had an average lead concentration equal to 506 mg/kg.

Other COIs

Fifty-five percent of the samples exceed copper background (182 mg/kg) while 72 percent exceed zinc background (136 mg/kg). Two samples exceeded the copper screening level (3,100 mg/kg). None of the samples exceeded the zinc screening level of 23,000 mg/kg.

Other COIs that exceeded screening levels in surface and subsurface samples included aluminum (one surface sample), cobalt, iron, manganese, and thallium (Tables 7-5 and 7-9). With the exception of thallium, the other metals occur at lower concentrations relative to their screening levels than arsenic and lead, and exceed screening levels less frequently.

7.2.3 Chaparral Gulch

This section describes the nature and extent of impacts to surface soil in the Chaparral Gulch system and important ancillary drainages including the Upper Chaparral Gulch (NR3), the MTP Blow Out Path (NR5), the Middle Chaparral Gulch (NR6), the Tailings Floodplain (NR8), and the Lower Chaparral Gulch (NR9). Figures 7-24 through 7-27B show sample locations, and lead and arsenic concentrations in surface soil and subsurface soil in these exposure areas. Tables 7-6 and 7-10 summarize the COI exceedances in surface soil and subsurface soil, respectively.

The primary sources of site impact to the Chaparral Gulch system are tailings associated with operations at the former Iron King Mine property including the MTP 1964 Blow Out and the former Small Tailings Pile, and tailings associated with operations at the former Humboldt Smelter property. Potential transport mechanisms for these materials are discussed in Section 8.

The first subsection below provides a description of the Chaparral Gulch depositional units as a basis for the nature and extent discussion that follows.

7.2.3.1 Chaparral Gulch Depositional Units

During the data gap phase of the RI, borings were advanced through the Recent and Quaternary deposits that fill Chaparral Gulch into the underlying Hickey Formation. Six unconsolidated units, described in Section 5.4.3, were observed and are mapped in the subsurface:

- Uppermost Channel Deposit (UCD)
- Tailings
- Humboldt Smelter Channel Deposit (HSCD)
- Lowermost Channel Deposit (LCD)
- Brown Clay
- Principal Fluvial Gravels (PFG)

Figure 7-28 summarizes the characteristics and relative stratigraphic position of these units. Geotechnical soil test results for materials in the Chaparral Gulch area are provided in Table 7-3.

The UCD, Humboldt Smelter tailings, HSCD, and LCD are interpreted to consist of mixed tailings and fluvial deposits based on stratigraphic location, physical characteristics, COI concentrations, and concentration ratios (Lockheed Martin SERAS, 2015). The Brown Clay and PFG are interpreted to be native fluvial deposits. Figures 7-29, 7-30, and 7-31 show the locations of section lines and show the geologic cross sections that illustrate the distribution of these units within Chaparral Gulch.

Material from each of these unconsolidated units was collected during the field exploration conducted in the Chaparral Gulch in 2014. Laboratory testing was performed to evaluate the gradation and plasticity of these materials. The UCD, HSCD, and LCD units are very similar, consisting of silty sand with gravel, and 20 to 40 percent silt. These units are well-graded from fine to coarse sand.

The PFG and Brown Clay units are generally immediately above the Hickey geologic formation. The PFG consists of well-graded sand and gravel with less than 15 percent silt and clay material. The Brown Clay unit appears to be a fat clay, meaning it has high plasticity, based on one sample that was tested. The PFG and Brown Clay have low concentrations of both lead and copper and are generally not impacted by site contamination (Appendix I Evaluation of Tailings Mixing).

The tailings deposits in the floodplain have been mapped in the subsurface from the Smelter Tailings Swale south to the Chaparral Gulch Dam; these deposits consist of an interbedded mixture of undisturbed and reworked tailings (Lockheed Martin SERAS, 2015). Figure 7-32 shows the thickness of tailings (Lockheed Martin SERAS, 2015). This isopach model was used to calculate volumes of tailings in the Tailings Floodplain and Smelter Tailings Swale, presented in Section 7.2.5.

In general, the reworked tailings have higher lead and zinc concentrations, and Pb:Cu and Zn:Cu ratios, suggesting that these deposits contain a mixture of tailings from operations at the former Iron King Mine property and the former Humboldt Smelter property (Appendix I). These findings suggest tailings from both properties have accumulated upstream of the dam.

The UCD extends from the MTP Blow Out Path (NR5) into the Tailings Floodplain (Figure 7-30, Section A-A’). It is thickest (approximately 13 feet) downstream of Third Street, but thins to about 5 feet before reaching the Smelter Tailings Swale (Lockheed Martin SERAS, 2015). The thinning of the UCD coincides spatially with the appearance of Humboldt Smelter tailings in the gulch (Lockheed Martin SERAS, 2015), which fill the channel downstream within the Tailings Floodplain area. The UCD occurs as discontinuous surface veneer in the floodplain (Lockheed Martin SERAS, 2015). Based on the observation of tailings present at the ground surface in the Middle Gulch, and elevated lead and zinc concentrations along with Pb:Cu and Zn:Cu ratios approaching those of the Iron King Mine tailings, the UCD is interpreted to contain Iron King Mine tailings (Appendix I).

In the floodplain, the combined thickness of the tailings, HSCD, and LCD units (tailings or mixed tailings and fluvium) increases from approximately 2 to 25 feet from the swale downstream to the Chaparral Gulch Dam (Figure 7-30, Sections A-A’ and B-B’). The thickness of oxidized (yellow, orange, red) Humboldt Smelter tailings decreases, and the thickness of reduced (green black) Humboldt Smelter tailings increases downstream in this direction as well. The reduced tailings deposits occur within the saturated portion of the sediments behind the dam. This color change coincides with a shallowing of the water table in the alluvial channel fill toward the dam, where it occurs as shallow as 3 feet bgs. The deposition of tailings, alluvium, and alluvium/tailing mixtures have filled the gulch to the crest of the dam. Based on lead and zinc concentrations, and Pb:Cu and Zn:Cu ratios similar to those of the Humboldt Smelter tailings, the HSCD unit is interpreted to contain little or no Iron King Mine tailings. The LCD unit has lead and zinc concentrations and ratios between those of Iron King Mine and Humboldt Smelter tailings, and are therefore interpreted to contain a mixture of Iron King Mine and Humboldt Smelter tailings (Appendix I).

7.2.3.2 NR3 Upper Chaparral Gulch

The Upper Chaparral Gulch (NR3) exposure area encompasses the Chaparral Gulch channel and the widening channel floodplain between Highway 69 and Third Street (see Figure 6-3). The channel is less topographically confined in this exposure area, and the stream grade shallows as it approaches Third Street; there is no culvert at Third Street. These conditions encourage sediment from upstream sources to accumulate in this area via braided channels during higher flow events (see Photograph 10 in Appendix A). The Upper Chaparral Gulch exposure area overlaps adjacent residential areas, and the distribution of sediments suggests this area acts as a floodplain.

Arsenic

Over 200 surface and subsurface samples were tested for arsenic and lead in NR3. Sample locations and arsenic concentrations are shown on Figure 7-24 for surface soils, and Figure 7-26A for subsurface soils. Figure 7-25 shows the sample locations and lead concentrations for surface soils; Figure 7-27A shows subsurface soil lead concentrations. Table 7-9 summarizes sample and concentration data.

For both surface and subsurface soils, about 83 percent of all samples had arsenic concentrations less than the screening level (194 mg/kg) and 62 percent were less than background (112 mg/kg). The average arsenic concentration for all samples within the Upper Chaparral Gulch equaled 126 mg/kg. The average for the 33 samples that exceeded the screening level equaled 392 mg/kg. The maximum arsenic concentrations were recorded at 215C-05 (991 mg/kg) and 215C-06 (835 mg/kg), both of which were surface samples located at the southern portion of the exposure area. The highest arsenic concentrations were found in surface samples within the southern half of the NR3 area. Only two subsurface samples exceeded the screening level for arsenic: CHU-SB12 at a depth of 5 feet (251 mg/kg), and CHU-SB05 at a depth of 4 feet (196 mg/kg). Both of these samples are located at the southern end of the exposure area.

Lead

Lead concentrations followed a similar pattern in NR3 as that found for arsenic. Ninety percent of the samples had lead concentrations less than the screening level (400 mg/kg), and about 29 percent had lead concentrations less than background (34.8 mg/kg). Of the 21 samples that exceeded the screening level, the average lead concentration equaled 938 mg/kg. The maximum lead concentrations were found at 215C-05 (3,080 mg/kg), 2444-06 (2,120 mg/kg), and 215C-06 (2,080 mg/kg). All of these samples were located on the left bank (north side of the gulch) near the surface.

Of the subsurface samples, only four exceeded the background level for lead (34.8 mg/kg) and none exceeded the screening level (400 mg/kg).

Only one sample exceeded the background concentration (182 mg/kg) for copper; 75 percent of the samples exceeded the background concentration (136 mg/kg) for zinc; none exceeded the zinc screening level (23,000 mg/kg).

Other COIs

Other COIs that exceeded screening levels in surface samples collected at Upper Chaparral Gulch (NR3) included iron (four surface samples) and thallium (one surface sample) (Tables 7-6 and 7-10). No other COIs exceeded screening levels in subsurface samples.

7.2.3.3 NR5 Main Tailings Pile 1964 Blow Out Path

NR5 was the main drainage pathway for tailings pond outfalls constructed at the MTP area throughout its operational history (see historical aerial photographs and interpretation in Appendix C). It was also the pathway for a portion of the tailings released by the MTP 1964 Blow Out discharged under the current location of Highway 69, into the JT Septic Facility property (NR4), across what is now Third Street, and into a gulley that runs east, parallel to Third Street, before merging downstream with Chaparral Gulch (Figure 6-3). Tailings have been observed within the blow out path during field reconnaissance and the EPA field investigations on the south side of Third Street in the middle of the exposure area. A small tailings pile is visible on the south side of the street across from Richards Lane. A photograph of the drainage at the Blow Out Path is provided in Appendix A (Photograph 9).

Arsenic and Lead

Sixty-three surface and subsurface samples were tested for arsenic and lead in NR5. Sample locations and arsenic concentrations are shown on Figure 7-24 for surface soils, and Figure 7-26A for subsurface soils. Figure 7-25 shows the lead concentrations recorded for surface soils, and Figure 7-27A shows subsurface soil lead concentrations at NR5. Table 7-9 summarizes sample concentration data.

For both surface and subsurface soils, about 57 percent of all samples had arsenic concentrations greater than the screening level (194 mg/kg), and 73 percent had concentrations greater than background (112 mg/kg). The average arsenic concentration for all samples within NR5 equaled 370 mg/kg. The average arsenic concentration for the 35 samples that exceeded the screening level (194 mg/kg) equaled 599 mg/kg.

The maximum arsenic concentrations were recorded at XRF-442 (2,270 mg/kg) and XRF-556 (2,060 mg/kg), both surface samples located near the center of the exposure area, just south of Third Street. Twenty-five percent of the samples, all surface samples, had arsenic concentrations greater than 500 mg/kg. Two subsurface samples (CHU-SB04 and CHU-SB02), located along Third Street at a small tailings pile across from Richards Lane, had arsenic concentrations (540 and 443 mg/kg) above background (112 mg/kg).

Lead concentrations followed a similar pattern in NR5 as that found for arsenic. Sixty-five percent of the samples had lead concentrations less than the screening level (400 mg/kg) and about 20 percent had lead concentrations less than background (34.8 mg/kg). Of the 22 samples that exceeded the screening level, the average lead concentration equaled 2,456 mg/kg. The maximum lead concentrations were found at XRF-556 (16,400 mg/kg) and XRF-553 (10,500 mg/kg), surface samples located on the south side of Third Street near the center of the exposure area. Of the subsurface samples, only one (CHU-SU-02 at 302 mg/kg) exceeded the background level for lead (34.8 mg/kg) and none exceeded the screening level (400 mg/kg).

Other COIs

Copper concentrations exceeded background (182 mg/kg) at two locations: XRF-439 (978 mg/kg) and XRF-454 (269 mg/kg). The average zinc concentration for all samples equaled 679 mg/kg. Over 94 percent of the samples exceeded the zinc background (136 mg/kg). None of the samples exceeded the zinc screening level (23,000 mg/kg).

7.2.3.4 NR6 Middle Chaparral Gulch

Middle Chaparral Gulch extends from Upper Chaparral Gulch at the Third Street overcrossing downgradient to the western edge of the Smelter Tailings Swale, where the Tailings Floodplain (NR8) begins (Figure 6-3).

The Middle Chaparral Gulch drains the Upper Chaparral Gulch located north of the former Iron King Mine. Aerial photographs taken in 1940, 1953, and 1964 show that the Middle Chaparral Gulch was also the drainage pathway for outfall discharges from tailings ponds located at the Iron King Mine (see Appendix C). These same aerial photographs show that the Upper and Middle Chaparral Gulch was essentially devoid of vegetation. The gulch was dammed off by 1940 and relatively heavy vegetation was apparent within the Tailings Floodplain (NR8) by 1953. In 1964, the MTP Blow Out occurred, sending tailings and impacted water down the Middle Chaparral Gulch. The gulch remained free from dense vegetation through 1973. By 2003, quite a bit of vegetation was visible within the main portion of the gulch.

The aerial photographs and the soils data suggest that Middle Chaparral Gulch (NR6) was impacted by tailings and impacted water from the former Iron King Mine operations that were transported under the Highway 69 culvert and through Upper Chaparral Gulch (NR3). Middle Chaparral Gulch (NR6) was also impacted by tailings discharged through NR4 and NR5 during the MTP 1964 Blow Out.

The site investigations show that the Middle Chaparral Gulch consists of several preferential, active channels incised into alluvial channel fill. Riparian vegetation is present on the banks where high-flow-event tailings deposition took place, suggesting multiple historical high flow events. Tailings are present within the gulch, along the banks of the middle and eastern edge of the channel, and outside the southern channel, suggesting floodwater had overtopped the channel, resulting in overbank deposition of the tailings and erosion of previously deposited tailings. Figure 5-6 indicates that the floodplain at the Middle Gulch is about 300 feet wide during a 100-year storm event, providing ample opportunity for deposition of overbank deposits. A photograph of the Middle Chaparral Gulch is provided in Appendix A (Photograph 11).

Arsenic and Lead

During the four RI investigations, 168 surface and subsurface soil samples were collected in the Middle Chaparral Gulch for analytical testing. Sample locations and arsenic concentrations are shown on Figure 7-24 for surface soils, and Figure 7-26A for subsurface soils. Figure 7-25 shows the lead concentrations recorded for surface soils. Figure 7-27A shows subsurface soil lead concentrations. Table 7-9 summarizes sample and concentration data.

For the entire Middle Chaparral Gulch, the average arsenic concentration equaled 331 mg/kg. About 47 percent of the surface and subsurface samples exceed the arsenic screening level (194 mg/kg), while 41 percent are below background (112 mg/kg). Of the 80 samples that exceeded the screening level, the average arsenic concentration equaled 632 mg/kg. The average concentration for surface samples and subsurface samples is about equal (333 vs. 327). As shown on Figure 7-24, all 27 surface samples that exceeded 400 mg/kg are located on the lower middle half of the exposure area.

The average arsenic concentration for the 18 subsurface samples that exceeded the screening level equaled 1,071 mg/kg. Arsenic screening levels were exceeded down to 13 feet bgs (CH-SB17). The maximum arsenic concentration (3,390 mg/kg) for subsurface soils was recorded at CH-SB11, located in the middle of the gulch near the top of NR6 at 7 feet.

Review of the surface and subsurface data shows that mining-impacted soil has been deposited intermittently with non-impacted material. This begins at the top of NR6 and is apparent throughout the exposure area. This trend is readily observed by inspection of Figure 7-26A for the following locations:

- At CH-SB02, located at the upper end of NR6 near Third Street
- At CH-SB15, located in the middle of the gulch about halfway between the upper and lower boundaries of NR6
- At CH-SB24, near the transition to the Tailings Floodplain (NR8)

Arsenic concentrations decrease to about background on the western edge of the gulch. However, at several locations on the western bank, elevated arsenic concentrations were found near the surface where high flow events have deposited tailings material. Examples include XRF 869 with a concentration of 661 mg/kg at the ground surface and XRF-875 with a concentration of 979 mg/kg at 0.91 foot. A few isolated areas are also present on the eastern side of the gulch where the braided stream system has deposited tailings material during flow events. XRF-588 on the east side of the gulch has an arsenic concentration of 569 mg/kg at the ground surface, decreasing to 161 mg/kg at 1.41 feet bgs.

Lead concentrations follow a pattern similar to arsenic concentrations within NR6. For all 168 samples, the average lead concentration equaled 489 mg/kg. About 26 percent of the samples had a lead concentration less than background (34.8 mg/kg), and 32 percent exceeded the screening level (400 mg/kg). Of the 54 samples that exceeded the screening level, the average lead concentration equaled 1,297 mg/kg. The average lead concentration of surface samples (530 mg/kg) was greater than that for subsurface samples (426 mg/kg). Review of the subsurface data shows the same layering of high and low lead concentrations as observed for arsenic.

The average lead concentration for the eight subsurface samples that exceeded the screening level equaled 3,125 mg/kg. Lead screening levels were exceeded down to 8.5 feet bgs. The maximum lead concentration (9,500 mg/kg) for subsurface soils was recorded at CH-SB11, located in the middle of the gulch near the upper end of NR6 at 7 feet.

The general material type in the stratigraphic profile (upgradient to downgradient) within NR6 is graphically depicted by Schematic Section A-A’ on Figure 7-30. UCD overlay PFG and bedrock, which consists of the Hickey Formation conglomerates. Lead or arsenic exceedances are associated with the UCD deposit, which is thickest in the central portion of the gulch and pinches out toward its margins. The UCD is thickest downstream of the confluence with NR5 and thins toward the Smelter Tailings Swale. Concentrations of arsenic and lead at depth decrease significantly at the bottom of the UCD material. Native alluvium (PFG) is present beneath the UCD and is locally exposed along the margins of the gulch (Figure 7-31, Sections E-E’). Brown Clay is also present at the margins of the gulch near the lower end of NR6 (Figure 7-31, Sections F-F’).

Other COIs

Only manganese in three surface samples exceeded the screening level at NR6 (Table 7-6). Manganese (11 samples) and iron (8 samples) exceeded screening levels in subsurface samples (Table 7-10). The other metals occur at lower concentrations relative to their screening levels than arsenic and lead, and exceed screening levels less frequently.

7.2.3.5 NR8 Tailings Floodplain

The Tailings Floodplain (NR8) is located downstream of Middle Chaparral Gulch (NR6), and extends from the southern boundary of the Smelter Tailings Swale (NR7) to below the Chaparral Gulch Dam (Figure 6-3). Appendix A includes photographs of the Smelter Tailings Swale (Photographs 16 through 19) and the Chaparral Gulch Dam (Photographs 20 through 22).

The Chaparral Gulch Dam impounds tailings and native alluvial deposits, and although the dam restricts groundwater flow in the saturated sediment wedge behind the dam, seepage discharges from the toe of the dam throughout the year with groundwater around 2 feet below the dam surface. The thickness of these deposits increases downstream approaching the dam, where the floodplain is more confined and the saturated thickness exceeds 20 feet. Little or no storage capacity remains behind the dam because of the accumulation of tailings and alluvium, which can now continue to migrate downstream to the Agua Fria River. Efflorescent salts are present on exposed tailings in the floodplain. These salts form by repeated cycles of wetting and drying, which concentrates metals in a highly mobile (and bioavailable) form. Photographs 16, 17, and 18 in Appendix A show these salts on the tailings floodplain.

The grain size of the tailings is predominantly silt and fine sand size, similar to the tailings in the MTP. However, much of the tailings contain medium to coarse sand, and fines of higher plasticity (Table 7-3). The tailings have likely picked up material from other soil units during transport into the Tailings Floodplain.

During the four RI investigations, over 350 surface and subsurface soil samples were tested in the Middle Chaparral Gulch. Sample locations and arsenic concentrations are shown on Figure 7-24 for surface soils and Figure 7-26B for subsurface soils. Figure 7-25 shows the lead concentrations recorded for surface soils, and Figure 7-27B shows subsurface soil lead concentrations at NR8. Table 7-9 summarizes sample and concentration data.

The samples with elevated concentrations of arsenic and lead along the southern bank are not as susceptible to erosion as the tailings near the main Chaparral Gulch channel because the southern bank materials were deposited during higher flow events. These samples had arsenic and lead concentrations indicative of tailings from the former Iron King Mine property. The samples downgradient of the Smelter Tailings Swale exhibit the Pb:Cu ratio indicative of Humboldt Smelter tailings deposited in this area. While the majority of the material throughout the Tailings Floodplain exposure area exhibits metals concentrations similar to Iron King Mine source material (very low in copper, high in lead and arsenic), deposits downgradient of the Smelter Tailings Swale exhibit a decrease in the Pb:Cu and Zn:Cu ratios on the north bank and main channel of the floodplain exposure area, as shown on Figures 7-5 and 7-6.

This change in ratios indicates separation of source tailings (Iron King Mine and Humboldt Smelter) materials at the ground surface.

Soil sampling was performed to a maximum depth of 27 feet bgs in the Tailings Floodplain. Concentrations of lead or arsenic exceeding background or screening levels at depth varied relative to the thickness of the tailings. Thus, as the thickness increases downgradient of Chaparral Gulch, so does the contamination. Below the tailings, the concentrations reduce to around background levels. There are some localized areas in the main channel and at the dam where the mixing of Iron King Mine and Humboldt Smelter tailing materials have produced more variable concentrations with depth.

Arsenic

The average arsenic concentration for 355 surface and subsurface soil samples equaled 377 mg/kg. About 34 percent of the samples had arsenic concentrations less than background (112 mg/kg), and 52 percent were less than the screening level. Of the samples that exceeded the screening level, the average arsenic concentration equaled 699 mg/kg.

The average arsenic concentration for surface and subsurface soils was about equal (359 mg/kg vs. 383 mg/kg). However, of the 72 samples that had arsenic concentrations greater than 500 mg/kg, 15 were surface samples (less than 2 feet bgs) and the remainder (57) were subsurface samples. For those samples that exceeded the screening level, the subsurface samples had an average arsenic concentration (816 mg/kg) almost double that of surface samples (484 mg/kg). Of the 33 samples that exceeded 1,000 mg/kg, 5 samples were obtained at the surface while the remainder (28) were subsurface. The maximum lead concentration (3,640 mg/kg) was recorded at a depth of 7.5 feet at Dam-SB05, located just upstream from the Chaparral Gulch Dam (see Figure 7-26B).

Inspection of Figure 7-24 shows that surface samples with elevated arsenic concentrations are present across the width of the gulch at the upper third of NR8. Within the lower half of NR8, most of the elevated arsenic concentrations in surface soils (greater than 400 mg/kg) are found on the western bank above the centerline of the gulch, indicating deposition of overbank impacted material during storm events.

The maximum arsenic concentrations for surface samples were recorded at XRF-485 (3,500 mg/kg) and CHF-SB20 (1,130 mg/kg), both located on the western bank in the lower portion of NR8, and at XRF-602 (1,120 mg/kg) located in the center of the gulch near the upper end of NR8. Above the Chaparral Gulch Dam, elevated arsenic is found on both the western bank (DAM-SB04 at 1,080 mg/kg) and within the center of gulch (HS-16 at 516 mg/kg). Figure 7-25 also shows that the arsenic concentrations of surface soils in the Smelter Tailings Swale (NR7) are uniformly lower than that observed in NR8.

Review of Figure 7-26B shows that arsenic concentrations in subsurface samples are different from that observed for the Middle Chaparral Gulch. Within the Middle Chaparral Gulch, several layers of impacted and non-impacted material were interlayered. In the Tailings Floodplain, the data indicate that a single layer of higher-arsenic-concentration material is present throughout the area, with lower-arsenic-concentration material located above and below. This high-concentration material was typically found 5 to 7 feet bgs; however, the layer was also found at several locations 2.5 to 3.5 feet bgs, to a maximum of 11 feet bgs near the center of the gulch at CHF-SB17.

Note that all these references to depth refer to the depth to the top of the sample. Also note that because the samples are taken at discrete intervals, it is not possible to clearly define the upper or lower limits of the high-concentration material.

Lead

The distribution of lead-impacted soils in NR8 is similar to that observed for arsenic. The maximum concentrations of lead were observed along the southern bank of the floodplain at locations most distal from the main channel of Chaparral Gulch, and downgradient from the berm breach of the Smelter

Tailings Swale. Lead concentrations were, in general, much higher compared to arsenic. About 19 percent of the samples had lead concentrations less than background (34.8 mg/kg), and 29 percent of the samples exceeded the screening level (400 mg/kg). Of the 103 samples that exceeded the screening level, the average lead concentration equaled 2,267 mg/kg.

As observed with respect to the arsenic distribution, many more subsurface (greater than 2 feet bgs) samples had high concentrations of lead compared to subsurface samples. Of the 49 surface and subsurface samples with lead concentrations greater than 1,000 mg/kg, 39 samples were subsurface, while 10 were surface samples. The largest lead concentration (45,900 mg/kg) was recorded at a depth of 10 feet bgs at Dam-SB01, located just upstream from the Chaparral Gulch Dam (see Figure 7-27B).

Similar to arsenic concentrations, the data indicate that a single layer with high lead concentrations is present through much of NR6, with lower lead concentrations above and below. For the most part, the elevated lead concentrations are found in the same layer as the elevated arsenic concentrations. Of the 102 samples within NR8 that recorded lead concentrations exceeding the screening level (400 mg/kg), only three samples had arsenic concentrations less than the arsenic screening level (194 mg/kg). For the 49 samples that had lead concentrations greater than 1,000 mg/kg, only two samples had arsenic concentrations less than 400 mg/kg. For these samples, the average Zn:Cu and Pb:Cu ratios were equal to 39 and 55 respectively, with 90 percent of both ratios greater than 7. As discussed in Section 8, these concentrations and ratios are indicative of Iron King Mine tailings.

Other COIs

With respect to copper, 87 percent of the 355 samples had copper concentrations less than background (182 mg/kg) and only four samples exceeded the screening level (3,100 mg/kg). Copper concentrations equal to 19,600 and 7,900 mg/kg were reported for samples XRF-593 and HSJ-548, located just down the hill from the Smelter Tailings Swale. These samples were also relatively low in arsenic (138 and 285 mg/kg) and marginally low in lead (326 and 538 mg/kg).

With respect to zinc, 13 percent of the samples had zinc concentrations less than background (136 mg/kg) and only one sample (DAM-SB01) located just upstream of the Chaparral Gulch Dam at a depth of 10 feet, exceeded the zinc screening level (23,000 mg/kg) with a concentration equal to 31,800 mg/kg. High zinc concentrations were also recorded for samples HSJ-535 and XRF-593 with concentrations of 15,500 and 14,700 mg/kg, both located just downgradient from the Smelter Tailings Swale.

Other COIs that exceeded screening levels (shown in Table 7-6) in surface samples collected at the Tailings Floodplain included cobalt (2 samples), iron (7 samples), manganese (6 samples), mercury (1 sample), and thallium (4 samples). Other COIs exceeding screening levels in subsurface samples included antimony (2 samples), cobalt (8 samples), iron (45 samples), manganese (28 samples), mercury (2 samples), and thallium (12 samples) (Table 7-10).

7.2.3.6 NR9 Lower Chaparral Gulch

The Lower Chaparral Gulch (NR9) exposure area is located downstream of the Tailings Floodplain (NR8) exposure area and extends to the confluence with the Agua Fria River (see Figure 6-3). Photographs of the Lower Chaparral Gulch are provided in Appendix A (Photographs 22 through 25). In this reach of the gulch, the stream has incised into the Precambrian bedrock forming a narrow steep-walled canyon.

Groundwater within the deposits behind the Chaparral Gulch Dam seeps beneath or around the dam abutments, providing a low but continuous surface water flow to Lower Chaparral Gulch. Just below the Chaparral Gulch Dam, and for a distance of about 50 yards downstream, red precipitate is present on the streambed and on surface soils adjacent to the stream (Photograph 22 in Appendix A). The precipitate is likely ferric hydroxide, resulting from groundwater discharge through the reduced tailings upstream of the dam. The Lower Chaparral Gulch is highly vegetated (Photograph 23 in Appendix A), suggesting that tailings below the dam are not present in large quantities in surface materials.

Approximately 900 feet downstream of the Chaparral Gulch Dam, upstream of its confluence with the Agua Fria River, tailings deposits are visible in the Lower Chaparral Gulch canyon (see Photographs 24 and 25 in Appendix A). These deposits were either associated with precursor operations at the former Agua Fria Mill (see Figure 2-2) or possibly discharges of tailings from upstream operations.

At the bottom of the gulch upstream of the Agua Fria River, Chaparral Gulch takes a very abrupt, almost 90-degree turn to the northeast. At this "elbow," there is evidence of extremely high energy/scour conditions that includes large rounded boulders and rocks, scour and erosional marks on the sides of the canyon, and channel deposits. About 200 feet downstream, the gulch flows into the Agua Fria River, which makes a sharp half-loop just upstream from the confluence.

During the RI investigations, 24 surface samples (less than 1-foot deep) were collected from the tailings deposits for testing. Sample locations and arsenic concentrations are shown on Figure 7-24. Lead concentrations are shown on Figure 7-25. Sample data are discussed below and summarized in Table 7-10.

Arsenic and Lead

The average arsenic concentration for the 24 surface samples equaled 539 mg/kg. Nine of the samples had arsenic concentrations less than background (112 mg/kg). For the 11 samples that exceeded the arsenic screening level of 194 mg/kg, the average concentration equaled 1,049 mg/kg. Three samples had arsenic concentrations greater than 1,000 mg/kg. A maximum arsenic concentration equal to 4,140 mg/kg was reported for XRF 514 at 0.91 foot bgs.

The average lead concentration equaled 649 mg/kg. None of the samples had lead concentrations less than background (34.8 mg/kg). For the seven samples that exceeded the lead screening level of 400 mg/kg, the average concentration equaled 1,827 mg/kg. Two samples had lead concentrations greater than 3,500 mg/kg (XRF-516 and XRF 514 at 6,060 and 3,760 mg/kg); both samples were collected at the ground surface.

Other COIs

Other COIs that exceeded screening levels in surface samples collected at NR9 included antimony (one sample), cobalt (two samples), manganese (one sample), and thallium (one sample) (Table 7-6).

7.2.4 Other Non-Residential Areas

This section describes the nature and extent of soil contamination at other non-residential exposure areas not previously described in the discussions for the former Iron King Mine property, the former Humboldt Smelter property, and Chaparral Gulch. The exposure areas include the following:

- Non-residential Properties located within or adjacent to the former Iron King Mine property
  - NR14 – South of Former Iron King Mine Property
  - NR15 – Auto Yard
  - NR20 – North of Chaparral Gulch
  - NR4 – JT Septic Facility
- Non-residential Properties located within or adjacent to the former Humboldt Smelter property
  - NR13 – Former Humboldt Smelter Property East of the Agua Fria River
- Non-residential Properties in Humboldt Proper
  - NR2 – Dewey-Humboldt Town Hall
  - NR2 – Humboldt Elementary School

Figure 6-3 shows the locations of these exposure areas.

7.2.4.1 Non-residential Properties within or adjacent to the Former Iron King Mine Property

Sample locations and arsenic concentrations in surface and subsurface soil within NR14, NR15, and NR20 are shown on Figures 7-15 and 7-16. Zinc concentrations for surface and subsurface samples are shown on Figures 7-17 and 7-18. Sample locations and arsenic and lead concentrations for surface soil collected from NR4 are shown on Figures 7-24 and 7-25. Table 7-7 summarizes the COI exceedances for surface soil. No subsurface samples were collected from NR14, NR15, NR20, or NR4.

NR14 South of Former Iron King Mine Property

NR14 adjoins the southern boundary of the former Iron King Mine property, south and downslope of the MTP and former Mineworks area. NR14 is within the Galena Gulch watershed, and other ancillary drainages emanating from Iron King Mine enter this exposure area. The area is vacant and undeveloped. Plates of the underground mine workings show that the workings extend southwest of the former Iron King Mine property boundary through NR14 at depths of 100 to 800 feet. Two of the primary shafts (Shafts 1 and 5) and associated waste dumps are located along bedrock benches and adjoining slopes of Galena Gulch in the area south of the former Fertilizer Plant (Figure 2-1) (Lockheed Martin SERAS, 2015). This the same area where, in 2014, ERT identified waste rock, three abandoned mine shafts, and one small horizontal portal. Review of historical aerial photographs (see Appendix C) indicate that small impoundments were located near processing facilities, mine shafts were located in the exposure area as early as 1940, and discharges from these facilities were conveyed toward Galena Gulch. In addition to dumping or placing waste rock, there is the potential for impacts from erosion of waste rock and tailings, and impacts from windblown MTP tailings during the winter months when the prevailing wind direction is from the northwest. Despite its current non-residential zoning, the area could be rezoned and developed for residential use. Only surface soil sampling has been performed in this exposure area.

The average arsenic concentration for 63 surface samples equaled 421 mg/kg. Sixty-three percent of the samples had arsenic concentrations below background (112 mg/kg). The average arsenic concentration of 26 samples that exceeded the screening level (194 mg/kg) equaled 903 mg/kg. Seven samples had arsenic concentrations that exceeded 1,000 mg/kg, with the largest concentration equal to 3,810 mg/kg reported for GAL-HA018. Five of these samples were collected adjacent to Galena Gulch in the area that historical aerial photographs indicate the presence of processing facilities, impoundments, mine shafts and waste rock. The other two surface samples, from GAL-HA002, were taken at a location identified as a drainage channel to a small dam located to the southeast of the sample location.

The average lead concentration for the 63 samples equaled 633 mg/kg. Twenty samples had lead concentrations less than background and 15 samples exceeded the screening level (400 mg/kg). The average lead concentration for these 15 samples equaled 2,513 mg/kg. Seven samples exceeded 1,000 mg/kg lead. All of these samples were taken from the area adjacent to Galena Gulch at the same locations that high arsenic concentrations were recorded.

All reported copper concentrations were less than background. Ten percent of the samples reported had zinc concentrations less than background. Ten samples had zinc concentrations greater than 1,000 mg/kg; none exceeded the zinc screening level.

NR15 Auto Yard

NR15 is the auto dismantling yard operated by Iron King Auto Salvage. NR15 is located adjacent to and south of the former Iron King Mine property and the lower MTP. Like NR14, this area is potentially susceptible to impacts from windblown MTP tailings during the winter months, when the prevailing wind direction is from the northwest. Only surface soil sampling has been performed in this exposure area. Figures 7-15 and 7-17 show the sample locations and concentrations for arsenic and zinc.

For the RI investigation, 26 surface samples were obtained from the exposure area for testing. None of the samples exceeded the arsenic background concentration (112 mg/kg). Five samples exceeded the background concentration for lead, ranging from 37 to 86.6 mg/kg. None of the samples exceeded the lead screening level of 400 mg/kg.

All copper concentrations were low, not exceeding 70 mg/kg. Zinc concentrations were also low; 12 of the samples were below background (136 mg/kg); the other three samples were less than 325 mg/kg. None exceeded the zinc screening level.

NR20 North of Chaparral Gulch

The NR20 exposure area is located north-northeast and upslope of Chaparral Gulch, and extends from Chaparral Gulch north-northeast to the adjacent ridgeline (see Figure 6-3). NR20 includes a small portion of the former Iron King Mine property currently zoned industrial, and vacant undeveloped land north of the former Iron King Mine property boundary zoned for limited residential use (Figure 5-16B). The ridgeline that forms the north-northeastern boundary of NR20 potentially served as a windbreak for windblown tailings from the former Iron King Mine property (discussed in Section 8). Only surface soil sampling was conducted in this exposure area.

The RI field investigation included collection of 116 surface samples in NR20. The samples were collected at the ground surface and to a maximum depth of 0.83 foot bgs. The average arsenic concentration for the 116 samples equaled 98 mg/kg. Sixty-six percent of the samples were below background (112 mg/kg). For the 15 samples that exceeded the arsenic screening level (194 mg/kg), the average arsenic concentration equaled 275 mg/kg. The maximum arsenic concentration of 609 mg/kg was reported for location IKM-HA137, located just north of Chaparral Gulch. As shown on Figure 7-15, several other samples that exceeded the screening level for arsenic were collected near IKM-HA137. The historical aerial photographs do not indicate that this area was used for ore processing or storage. Arsenic levels north of the MTP are highest on the upslope to the first ridge, at the ridgeline, and to some extent on the backslope over the top. Levels at the next ridge are considerably lower and more variable, and by the third to fourth ridges and slopes, levels of arsenic have fallen to background levels. It appears that the slopes to the ridges serve as windbreaks, with the first slope ridge intercepting much of the tailings migrating from the MTP.

Sixty-one samples had lead concentrations less than background; none of the samples exceeded the screening level. The average lead concentration equaled 54 mg/kg.

Copper and zinc concentrations were low; copper averaged 39 mg/kg, zinc averaged 234 mg/kg. All copper concentrations were less than background (182 mg/kg). Fifty-two samples had zinc concentrations less than background (136 mg/kg). The maximum zinc concentration equaled 821 mg/kg, far less than the zinc screening level (23,000 mg/kg).

NR4 JT Septic Facility

The NR4 exposure area is a commercial facility located east of Highway 69 and just west of the NR5 MTP Blow Out Path exposure area (see Figure 6-30). Tailings, likely finer-grain size, released by the 1964 MTP Blow Out discharged under the current location of Highway 69 into this exposure area. Tailings were observed in surface soils in uncovered portions of the property.

Nine soil samples were collected from this property from the ground surface to a depth of 0.91 foot. Sample locations and arsenic and lead concentrations are shown on Figures 7-24 and 7-25.

The average arsenic concentration for the nine samples equaled 713 mg/kg. For the seven samples that exceeded the screening level (194 mg/kg) the average arsenic concentration equaled 980 mg/kg. A maximum arsenic concentration of 1,940 mg/kg was recorded at XRF-417, located on the eastern side of the property near Third Street.

The average lead concentration for the nine samples equaled 1,183 mg/kg. Eight of the nine samples exceeded background (34.8 mg/kg), five of the nine exceeded the screening level (400 mg/kg). Of the samples that exceeded the screening level, the average lead concentration equaled 1,954 mg/kg. The maximum lead concentration of 3,100 mg/kg was recorded at XRF-417.

The average copper concentration equaled 101 mg/kg, all samples except one had copper concentrations less than background (182 mg/kg). The average zinc concentration equaled 945 mg/kg. Eight of the nine samples exceeded background (136 mg/kg) for zinc; none exceeded the screening level (23,000).

7.2.4.2 Non-residential Properties within or adjacent to the Former Humboldt Smelter Property (NR13)

This category includes only the exposure area designated for the former Humboldt Smelter property on the east side of the Agua Fria River. The exposure area is shown on Figure 6-3.

NR13 Former Humboldt Smelter Property East of the Agua Fria River

NR13 includes the undeveloped, vacant portion of the former Humboldt Smelter property east of the Agua Fria River, as well as adjacent undeveloped land (see Figure 6-3). Based on proximity to the former Humboldt Smelter property, it is susceptible to impacts from windblown tailings, dross, and historical smelter stack emissions.

Eleven near-surface samples (at the ground surface, and at about 0.41 foot) were collected and tested within NR13 during the RI investigation. Sample locations and copper and zinc concentrations are shown on Figures 7-19 and 7-22.

Arsenic concentrations were less than background (112 mg/kg) for 8 of the 11 samples, and less than the screening level (194 mg/kg) for the other 3 samples.

Lead concentrations exceeded background for 10 of the 11 samples. Two samples taken at XRF-622 on different dates, both at the ground surface, had lead concentrations equal to 424 and 414 mg/kg. These were the only samples that exceeded the lead screening level (400 mg/kg).

Seven of the 11 samples exceeded background (182 mg/kg) for copper. The maximum copper concentration (1,120 mg/kg), recorded for a surface sample at XRF-622, was less than the screening level (3,100 mg/kg). Seven of the 11 samples exceeded background (136 mg/kg) for zinc. The maximum zinc concentration (568 mg/kg) was less than the screening level (23,000 mg/kg).

7.2.4.3 Non-residential Properties in Humboldt Proper

This exposure area (NR2) includes the Dewey-Humboldt Town Hall and the Humboldt Elementary School. The locations are shown on Figure 6-3. Figures 7-1 and 7-2 show sample locations, and arsenic and lead concentrations.

NR2 Dewey-Humboldt Town Hall

This part of NR2 is a series of commercial buildings in Humboldt Proper that includes the Dewey-Humboldt Town Hall and a parking lot. Due to its proximity to the former Humboldt Smelter property, this exposure area may have been susceptible to potential impacts from windblown tailings, dross, and historical smelter stack emissions.

Eleven surface soil samples were collected from the NR2 Dewey-Humboldt Town Hall area. Average arsenic and lead concentrations equaled 13 and 12 mg/kg. All samples had concentrations less than background for arsenic (112 mg/kg) and lead (34.8 mg/kg).

Average copper and zinc concentrations equaled 25 and 70 mg/kg. All samples had concentrations less than background for copper (182 mg/kg) and for zinc (136 mg/kg). Table 7-7 provides a summary of the data.

NR2 Humboldt Elementary School

This part of the NR2 exposure area is the Humboldt Elementary School, the only school in Humboldt Proper. The school is potentially susceptible to impacts from windblown tailings, dross, and historical smelter stack emissions from the former Humboldt Smelter property.

Thirty-two surface soil samples were collected from the NR2 school grounds. Average arsenic and lead concentrations equaled 20 and 32 mg/kg. All samples had concentrations less than background for arsenic (112 mg/kg). Seventeen samples had lead concentrations less than background (34.8 mg/kg). The maximum lead concentration equaled 68.3 mg/kg, substantially lower than the lead screening level (400 mg/kg).

Average copper and zinc concentrations equaled 38 and 136 mg/kg. All samples had concentrations less than background for copper (182 mg/kg). Seventeen samples had concentrations less than zinc background (136 mg/kg). The maximum zinc concentration of 286 mg/kg was substantially lower than the zinc screening level (23,000 mg/kg). Table 7-7 provides a summary of the data.

7.2.5 Source Material Volumes

This section summarizes the source material volume estimates developed for the former Iron King Mine and Humboldt Smelter properties using the data discussed in previous subsections. Source material is defined as media that includes or contains hazardous substances, pollutants, or contaminants that act as a reservoir for migration to other media or for direct exposure (EPA, 1991b). Volume estimates were developed as part of the Initial RI (EA, 2010) and the Data Gap RI (Lockheed Martin SERAS, 2015). A revised estimate of the MTP volume was also performed as part of the current RI Report preparation.

The volume estimates will be re-estimated during the FS. Volumes will be subdivided by exposure area to the extent feasible, and overburden will be incorporated into the volume estimates for excavation alternatives. Volumes estimated by EA during Phase 1 of the RI will be reevaluated using the data obtained during the RI Phases 2 through 4.

EPA originally subdivided source material volume estimates into two categories (EPA, 1991b):

- **Principal threat wastes:** Source materials that are considered highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment if exposure were to occur.
- **Low-level threat wastes:** Source materials that exhibit low toxicity and low mobility, and can be reliably contained or would present a low risk to human health or the environment if exposure were to occur.

The categories of principal threat wastes and low-level threat wastes for source materials are presented in this section, as cited in previous investigation reports, but this distinction is not intended to be carried forward through the risk assessments or the FS.

Table 7-24 summarizes key information regarding the volume estimates, as well as areal extent and depths, while Table 7-25 provides additional information regarding the volume calculations in the Smelter Tailings Swale, Tailings Floodplain, and Chaparral Gulch. Tables 7-2 and 7-3 provide physical characteristics of these materials.

7.2.5.1 Former Iron King Mine Property and Adjacent Galena Gulch

NR17 Main Tailings Pile

The Iron King Mine MTP is the largest stockpile of source materials onsite. The volume of the Iron King Mine MTP was refined as part of this RI by comparing the historical ground surface with a current topographic survey. Triangulated irregular network (TIN) surfaces were created for the current and historical ground surfaces using AutoCAD Civil3D (by Autodesk, Inc.) as discussed below. The TIN for the historical ground surface was subtracted from the current existing ground surface to obtain the total fill volume over the pre-mining ground surface.

The pre-mining ground surface was modeled using contours digitized from USGS 15-minute quadrangle maps from the 1940s. Four USGS quadrangle maps were used to provide coverage for the entire portion of the MTP, with dates of 1944, 1948, and two maps dated 1949. These were the earliest dates available of suitable quality for the analysis. As discussed in Section 2.3.2.2, the MTP developed as a series of smaller impoundments within two shallow drainages that were tributaries to Chaparral Gulch. Two tailings piles are visible in the 1949 USGS quadrangle map used for the northwestern corner of the MTP. However, the volume attributable to these initial tailings deposits is well within the uncertainty range of the USGS topography, which had a 50-foot contour interval. To improve the accuracy of the estimate, the 1940s contours were adjusted to be consistent with the measured elevation of native ground (Hickey Formation) determined during the following:

- 2012 Phase 1 Subsurface Exploration CPT (GEI, 2012)
- Soil borings advanced through the MTP as part of the Initial and Supplemental RIs (EA, 2010 and unpublished)
- Soil borings advanced through the MTP as part of the Data Gap RI (Lockheed Martin SERAS, 2015)

The current ground surface was obtained from an aerial survey performed for NAI by Cooper Aerial Survey, Phoenix, Arizona, in 2004 of the former Iron King Mine property (NAI, 2004). In addition, Granite Mountain Survey performed an aerial survey in 2013 on behalf of the Yavapai County GIS Department. Both the 2004 and 2013 topographic surveys provide 2-foot contour interval mapping. For comparison purposes, the volume of the MTP was calculated using both the 2004 and 2013 survey data as the current ground surface, and the difference in the calculated volume was less than 1 percent (less than 12,000 yd^3).

The volume of the MTP is estimated at approximately 3.5 million yd^3. There is a degree of uncertainty in the volume calculation because the topography for the historical ground surface used in the calculation was based on a 50-foot contour interval. Therefore, the actual volume should be considered to be plus or minus 0.5 million yd^3 from the estimated value. In the initial phase of the RI, EPA classified this material as principal threat waste.

Other Source Material Areas

In the Initial RI, source material volumes were calculated for several different areas of the former Iron King Mine property (EA, 2010). This was accomplished by combining chemical data with lithologic information obtained from surface, subsurface, and deep soil borings drilled during the Initial RI. Source material volumes were calculated for the following exposure areas. As discussed in Section 6.6, the exposure area designations in this RI Report differ from area designations in the Initial RI (EA, 2010); where different, both are provided.

- **NR16 Former Mineworks Area** (referred to as “Iron King Mine Operations Area” in the Initial RI):
  - Low-level threat waste: 90,800 yd^3
    - Assumptions for waste rock and tailings-impacted soil, which was estimated to cover one-fourth of the area: 700 by 1,400 feet with an average depth of 10 feet.
- **NR16 Former Fertilizer Plant**
  - Low-level threat waste: 11,100 yd^3
    - Assumptions for impacted surface soil: 300 feet by 500 feet with an average depth of 2 feet.

- **NR18 NAI Operations Area** and associated retention ponds (referred to as "Iron King Mine Plant" in the Initial RI):
  - Low-level threat waste: 19,200 yd^3
    - Assumptions for tailings-impacted surface soil, which was estimated to cover one-half of the area: Areal extent of 800 by 500 feet with an average depth of 2 feet (volume of 14,800 yd^3).
    - Assumptions for tailings-impacted surface soil and sediment in the three retention ponds: Three areas with an areal extent of 200 by 100 feet with an average depth of 2 feet (volume of 4,400 yd^3).
- **NR19 North of MTP** (referred to as "Iron King Mine Operations Area – Miscellaneous" in the Initial RI)
  - Low-level threat waste: 7,400 yd^3
    - Assumptions for impacted surface soil, which was estimated to cover one-twentieth of the area: 1,000 feet by 2,000 feet with an average depth of 2 feet.
- **NR14 South of Former Iron King Mine Property** (Galena Gulch)
  - Low-level threat waste: 37,000 yd^3
    - Assumptions for impacted surface soil: 500 feet from north to south and 1,000 feet from east to west with an average depth of 2 feet.

The estimated volumes were based on the surface area and depth of materials observed in borings drilled. Due to the inherent uncertainties in these estimates, EPA applied an uncertainty factor to these estimates of +/- 30 percent (EA, 2010).

7.2.5.2 Former Humboldt Smelter Property and Adjacent Chaparral Gulch

The volume of source materials on the former Humboldt Smelter property and in Chaparral Gulch was estimated by EA (2010) and ERT (Lockheed Martin SERAS, 2015). The ERT volume estimates, where available, were used preferentially to the EA estimates, as the ERT estimates incorporated data obtained during the more recent 2013 to 2014 ERT data gap field investigation.

Smelter Tailings Swale, Tailings Floodplain, and Chaparral Gulch Contaminated Deposits (from Third Street to Dam)

The volume of tailings and Chaparral Gulch deposits from Third Street to the Chaparral Gulch Dam was determined as part of the ERT Data Gap RI. The volume estimates are summarized in Table 7-25.

Solid-body 3D visualization models were developed using the Rockworks16 software package. The 3D models were based on the CSM of the hydrostratigraphy (see Section 5.4. The hydrostratigraphic model assumes the top of the Quaternary deposits (PFG or Brown Clay) represents the "pristine arroyo," and overlying channel deposits filled the Chaparral Gulch arroyo after the smelting and mining activities began. These overlying channel deposits include the UCD, tailings, HSCD, and LCD. The hydrostratigraphy was developed from logs of 115 boreholes advanced as part of the ERT Data Gap RI. The extent of contamination was defined from XRF results for approximately 500 samples, and used a threshold of arsenic concentrations greater than 200 mg/kg and/or lead concentrations greater than 400 mg/kg. Two-foot topographic survey data were obtained from Yavapai County for inclusion in the 3D geologic model, as well as 2014 survey data collected by Granite Basin Engineering, Inc., for the Smelter Tailings Swale. See Section 4.5 for a summary of the ERT field investigation methods and objectives. The details of the 3D modeling method and the approach used for the hydrostratigraphic superposition and volume estimates are included in Appendix 6-A of the ERT report (Lockheed Martin SERAS, 2015).

The total volume of channel deposits in Chaparral Gulch from Third Street to the dam was estimated using the 3D visualization model and Rockworks software. The volume estimate includes UCD, tailings, HSCD, and LCD channel deposits, in the following exposures areas: Upper Chaparral Gulch (NR3), the MTP Blow Out Path (NR5), Middle Chaparral Gulch (NR6), the Smelter Tailings Swale (NR7), and Tailings Floodplain (NR8). The estimate does not include Lower Chaparral Gulch (NR9). The modeling results suggest that 349,150 yd^3 of channel deposits (UCD, tailings, HSCD, and LCD) have filled the Chaparral Gulch arroyo after smelting and mining activities began. Of this volume, 280,610 yd^3 was estimated to exceed the threshold concentrations of 400 mg/kg lead or 200 mg/kg arsenic. ERT separated the volume of contaminated fill deposits by depth, as summarized in Table 7-25 and Figures 6-6A, 6-6B, and 6-6C of the ERT report. An estimated 97 percent of the contaminated deposits are located between ground surface and 10 feet in depth. The current presentation of the data in the ERT report does not allow this volume to be separated by exposure area; this can be performed as part of the FS using the Rockworks software.

The thickness, horizontal extent, and volume of the tailings were also estimated using a 3D tailings isopach model. The volume of tailings is a subset of the total volume of channel deposits discussed in the preceding paragraph. The tailings isopach model incorporated information from the hydrostratigraphic model and borehole lithology, and was not limited to samples that exceeded the concentration thresholds. The top domain of the isopach model was delineated by the top of the tailings; the bottom of the isopach model was delineated by the top of the Brown Clay (see hydrostratigraphic unit description in Section 5.4). The model-defined extent of tailings (see Figure 7-32) was limited to the Middle Chaparral Gulch (NR6), Smelter Tailings Swale (NR7), and Tailings Floodplain (NR8) exposure areas. The total volume of tailings was estimated as 187,380 yd^3, with the Tailings Floodplain containing the largest proportion of the estimated tailings volume (see Table 7-25). An estimated 61 percent (or 114,000 yd^3) of the tailings exceeded the concentration thresholds of 200 mg/kg arsenic and/or 400 mg/kg lead.

NR9 Lower Chaparral Gulch (from Dam to Confluence with the Agua Fria River)

In the initial phase of the RI, EPA estimated the volume of tailings and tailings-impacted sediment in Lower Chaparral Gulch downstream of the dam (NR9) at 1,800 yd^3 (2010). This was calculated with the assumption that the impacted material is approximately 1,200 feet from northwest to southeast, 2 feet deep on average, and extended over a narrow width (20 feet) in this portion of the gulch, which consists of a narrow steep-walled canyon (EA, 2010).

NR10 Agua Fria Tailings Pile

In the initial phase of the RI, EPA developed an estimate of the volume of the Agua Fria Tailings Pile (NR10) at 6,700 yd^3 assuming an area of approximately 300 feet from northeast to southwest and 150 feet from north to south, and an average depth of 4 feet. No subsurface samples have been collected in this exposure area, however, and there is a high level of uncertainty with this volume estimate. A photograph of the Agua Fria Tailings Pile is provided in Appendix A (Photograph 37).

NR11 and NR12 Dross and Contaminated Soil

A primary objective of the data gap dross investigation performed in 2014 (Section 4.5.5.1) was to determine the spatial extent and volume of the dross present at the former Humboldt Smelter property (Lockheed Martin SERAS, 2015). Approximately 300 unconsolidated samples were collected from hand-auger and boring locations to determine the spatial extent and volume of the dross material and the volume of the total contaminated soil (combined dross and non-dross material) in the former Pyrometallurgical Operations area (NR11) and adjacent Smelter Plateau (NR12).

The dross volume was estimated by integrating the thickness of dross, as defined by the boring logs, over the dross area using a hollow-body volume estimate. The volume of dross in NR11 and NR12 was calculated as approximately 47,000 yd^3.

The volume of the total contaminated soil was estimated using XRF analytical results to build a solid body model, including both dross and non-dross material, with arsenic concentrations exceeding 200 mg/kg and/or lead concentrations exceeding 400 mg/kg. The total volume of contaminated soil in NR11 and NR12 was estimated at approximately 207,000 yd^3. The 207,000 yd^3 estimate includes the 47,000 yd^3 estimated to be dross.

ERT noted that the volume of contaminated soil was presumed low because the extent of contamination to the south and southeast on the Smelter Plateau was undefined. It also should be noted that there were inconsistencies in ERT's sample classification of material as dross, non-dross, or other material (for example, tailings) in the text compared to the electronic data deliverables of the Lockheed Martin SERAS (2015) report. The ERT volume estimate was not extensively reviewed or refined as part of this RI Report.

NR11 and NR12 Slag

Slag present on the former Humboldt Smelter site is found in piles of vitrified glass-like material within the eastern portions of the property adjacent to the Agua Fria River. In the Initial RI, EA estimated the volume of the slag piles within NR11 and NR12 at 1.7 million yd^3 (EA, 2010). The slag pile volume estimate is highly uncertain as the depth and thickness of the material is unknown. This number is calculated based on the assumption that the slag has impacted an area of approximately 1,000 feet from north to south and 300 feet from east to west. EA assumed that the thickness of the slag overhanging the Agua Fria River is 150 feet (EA, 2010). A review of the topography indicates that the maximum difference between the elevation of the top of the slag pile and the Agua Fria River is less than 100 feet. Therefore, this thickness is overestimated, and the volume of slag as well as other source materials will be reevaluated during the FS.

7.3 Soil: Residential Areas

The following subsections summarize the nature and extent of impacts to soil on residential properties located within or near the APSI. Potential site-related sources of soil contamination in the residential areas include windblown dust, tailings, dross, and impacted soil from the former Iron King Mine and Humboldt Smelter properties; particulate stack emissions associated with historical smelter operations; surface water transport and deposition along Chaparral Gulch; spills and material releases along historical rail routes; and use of waste material (tailings, waste rock) as fill at residential properties. Development of the area near the former Iron King Mine and Humboldt Smelter properties during the more than 100 years since operations began has resulted in the redistribution of contamination.

In addition, there are numerous non-site-related sources that have impacted concentrations. Naturally occurring arsenic (and other metals) is associated with silicic volcanic materials such as rhyolite, which are widely present within the region. Fill has been imported from quarries with naturally elevated concentrations of arsenic, and cut-and-fill activities have occurred in areas of naturally elevated concentrations of arsenic east of the Agua Fria River. Non-site-related sources of lead include use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires.

The result of site-related and non-site-related sources of metals, in addition to the redistribution of contamination during development, has resulted in a complex patchwork distribution of metals in residential areas. For this reason, multiple phases of sampling were performed in residential areas, with the most extensive sampling efforts occurring between 2008 and 2012, and between 2013 and 2014. In total, approximately 6,300 soil samples were collected from residential properties within the APSI. As discussed in Section 6, the APSI was defined as the area surrounding the mine and smelter within which a potential site impact may have occurred due to blowing tailings or smelter stack emissions. EPA derived the APSI based on multiple lines of evidence. These included evaluations of background metals concentrations, ratios of metals concentrations in shallow and deep soils, and statistical evaluations of arsenic, lead, and concentrations of key indicator metals zinc and copper. The detailed derivation of the APSI can be found in Appendix F. EPA's approach to investigating impacts from the Site to residential soils focused on those yards that lie within the APSI.

Two sampling approaches were used to characterize residential areas within the APSI (Lockheed Martin SERAS, 2015), as discussed in Section 6.6:

- Properties located closer to the former Iron King Mine or Humboldt Smelter properties, or where previous sampling indicated the presence of elevated concentrations of COIs, were designated as "RYSR" areas. This acronym stands for "Residential Yard-Specific Risk." For RYSR areas, sampling was performed and analytical results were evaluated on a yard-by-yard basis. Each yard within RYSR areas (for which EPA could obtain legal permission to sample the property) was sampled with 10 to 20 samples depending on the size of the yard size, and EPA subsequently developed an incremental excess (site-related) risk specific to each yard. This yard-specific evaluation for RYSR areas can be found in the Risk Assessment in Section 9 this RI Report (and related appendices).
- Properties located near the boundary of the APSI were less likely to be impacted by site-related impacts, based on distance from the former Iron King Mine and Humboldt Smelter operations. Even though these areas were within the APSI, when the investigation began it was possible that any impacts from the sites were minimal. EPA therefore followed a screening approach for these areas, which were designated as "RSAR" areas. This acronym stands for "Residential Screening Area Risk." These areas at the periphery of the APSI were divided into manageable screening subareas, labeled A through J. Each screening area contained many contiguous properties. The investigation plan included the contingency that if the overall site-related risk, or even high individual values, emerged from the screening investigation, then the screening area would be converted to an RYSR area and all properties in the area would be sampled. If the area characterized as a whole posed only low residential risks and had no significantly elevated levels, then yard-by-yard sampling would be unnecessary. Each screening area was sampled and a screening evaluation was done for each screening area. EPA took care to ensure that no single property received too many samples, and that samples were reasonably and representatively spread across the entire area. An examination was performed of both the statistical characteristics of the data distribution and the concentration values at all individual points.

As discussed in Section 6.6, a sufficient number of samples were collected from each RSAR or RYSR area to estimate the areal average concentration (as represented by the 95 percent UCL of the mean) for that area (see also Section 11 of the ERT report, included as Appendix F of this RI Report). This concentration is referred to as the exposure point concentration, or EPC, and is primarily used to assess human health risks (see Section 9.4.2), but is also used here to describe the extent of arsenic and lead contamination on an exposure-area-specific basis for each RSAR or RYSR area.

The findings of nature and extent characterization for arsenic and lead in soil in the residential areas are summarized in the following figures, tables, and Appendix J. These are intended to provide a perspective for identifying the nature and extent of contamination. They are not intended to infer the existence or absence of unacceptable risk because they do not address cumulative risk or consider contributions from background levels. The risk assessments conducted as part of this RI (Sections 9 and 10) provide site-specific estimates of risk intended for management decision making.

- Figures 7-33 and 7-34 illustrate the distribution of lead and arsenic, respectively, in surface soil in the RYSR and RSAR exposure areas. For context, these figures also show lead and arsenic concentrations for the Iron King Mine and Humboldt Smelter source areas. For the purposes of this RI, surface soil is defined as samples with a beginning depth less than or equal to 2 feet bgs. At most locations, samples were collected at both 0 and 1 foot bgs. Although these data are available in the database (Appendix G), only the maximum value is presented on Figures 7-33 and 7-34.

- Figures 7-35 and 7-36 show the EPCs for arsenic and lead, respectively, for each RSAR and each yard in the RYSR exposure area.
- Tables 7-13 through 7-15 summarize soil analytical results for RYSR and RSAR areas. Table 7-15 provides information on potential sources of contamination and additional field observations identified as part of the fate and transport evaluation in this RI (see Section 8), the ERT data gap investigation and residential hot spot assessment (see Section 11 of Lockheed Martin SERAS, 2015), and/or information provided by EPA.
- Appendix J includes more detailed information regarding the residential sampling:
  - Detail maps that illustrate lead and arsenic concentrations in soil samples collected at each yard and a tabulated summary those results.
  - Table J-1 provides a cross-reference of EPA yard numbers to street, address, and assessor's parcel numbers.
  - Table J-2 summarizes COI exceedances for each residential yard.

The nature and extent of lead and arsenic in soil at RYSR and RSAR exposure areas are discussed in the following sections (first as a group, and then for each exposure area). As discussed in Sections 3 and 6, soil removal actions were performed at selected residential and municipal properties in 2006 and 2007 by Brown and Caldwell on behalf of Ironite Products Company (Brown and Caldwell, 2007) and in 2011 by EPA (E & E, 2012). To allow a comprehensive evaluation of the current and historical nature, extent, and contaminant transport pathways, pre-removal concentrations are used in this nature and extent evaluation. In other words, in certain small areas, some of the points and associated concentrations shown on the figures are in areas that have been subsequently cleaned up by EPA during removal actions as discussed in Appendix D. For completeness, however, the pre-removal concentrations are shown.

7.3.1 Lead and Arsenic Concentrations in Residential Areas

To provide a general perspective on the nature and extent of metals in surface soil at residential properties, Table 7-13 summarizes the number of RYSR and RSAR properties with soil concentrations exceeding screening levels and background UTLs. Details specific to the RYSR and RSAR exposure areas are discussed below in Sections 7.3.2 and 7.3.3.

The largest concentrations of arsenic in soil samples from residential areas were detected in RYSR exposure areas surrounding the former Humboldt Smelter property, and areas that overlap or are adjacent to the Upper or Middle Chaparral Gulch (Figure 7-33). As discussed in Section 7.1.2, contamination is primarily limited to the surface (top 2 feet) as shown on Figures 7-7 through 7-10.

Specific observations regarding the distribution of arsenic in surface soil in residential areas are provided below (refer to Figures 7-33 and 7-35 for illustrations of these observations). It is essential to note that this discussion uses general comparisons to screening levels to illustrate nature and extent of contamination. However, it is the much more detailed and comprehensive site-specific risk characterization provided in Section 9 of this report that must be used to assess the need for cleanup at any individual yard; *not* the discussion in this section.

- Arsenic concentrations in RYSR properties range from 1.8 to 1,630 mg/kg. The majority of residential yards within the APSI have arsenic concentrations that are below background and below screening levels. Approximately 10 percent of the RYSR samples have concentrations that exceed background and 3 percent of concentrations that exceed the screening level (Table 7-13). Concentrations in RSAR areas were much lower, as discussed in Section 7.3.3.

- Elevated arsenic concentrations (exceeding background or screening levels) in Humboldt Proper occur in a linear area along the historic rail line entering the former Humboldt Smelter property. The distribution of elevated arsenic concentrations in this area is consistent with historical spills during loading, unloading, and transferring of material for operations at the former Humboldt Smelter property along the rail right-of-way and the subsequent redistribution of these materials during redevelopment of this area. The yards along Sweet Pea Lane closest to the former Humboldt Smelter property have been remediated (Section 3.4). However, there are yards farther north along the same rail pathway alignment, and outside the area that was subject to remediation, that continue to exhibit elevated concentrations of lead in residential soils. It is noted that many but not all of these yards are not presently occupied.
- Elevated arsenic concentrations occur in yards that overlap Upper Chaparral Gulch (NR3) and Middle Chaparral Gulch (NR6). The distribution of arsenic in this area appears consistent with the migration of tailings-impacted sediment from the Iron King Mine property via Chaparral Gulch and deposition of those sediments in the widening floodplain of Chaparral Gulch upstream of Third Street. Elevated arsenic concentrations also occur in yards 2214 and 252, which overlap Chaparral Gulch upstream and downstream, respectively, of NR3. Elevated arsenic observed in yards 252 (and 127) could be attributed to both transport via Chaparral Gulch or the MTP Blow Out.
- A cluster of elevated arsenic concentrations has been found immediately north (downwind) of the former Pyrometallurgical Operations area (NR11). The elevated arsenic detections in this area are consistent with windblown transport mechanisms, historical stack emissions from the former Humboldt Smelter property, and transport of sediment in runoff from the operations area.
- Elevated arsenic concentrations occur in yards on the east side of the Agua Fria River, generally south of Lazy River Drive (for example, in yard 1903). This is an area of differing geology that is characterized by higher naturally occurring concentrations of arsenic (see Section 6.2), as well as other metals such as iron and manganese. Hot spot sampling and assessment of multiple parcels in this area indicate that these elevated concentrations are likely naturally occurring. The geology in this area is naturally higher and more variable for arsenic than geology west of the Agua Fria River and/or Highway 69. Virtually all the properties closer to the smelter from these localized yards have much lower levels of arsenic.
- A cluster of elevated arsenic concentrations is observed east of the Smelter Plateau (near exposure area NR13) across the Agua Fria River (for example, in yards 167A and 2901). The prevailing wind direction is from the south and southeast for most of the year, but during the winter months, the prevailing wind direction is from the northwest. In addition to elevated naturally occurring concentrations of arsenic in the geology east of the Agua Fria River, the elevated arsenic concentrations in these areas may be associated in part with the deposition of historical stack emissions or windblown tailings that accumulated during the winter months.
- Clusters of samples with arsenic concentrations that exceed the screening level are locally concentrated at specific yards, but sampling from the surrounding yards shows concentrations there are generally consistent with background concentrations. These yards are discussed in further detail below.

Similar to arsenic, lead concentrations in surface soil that exceed background or screening levels in the RYSR and RSAR exposure areas occur in multiple areas surrounding the former Humboldt Smelter property, and in residential areas that overlap or are adjacent to the Upper or Middle Chaparral Gulch (Figures 7-34 and 7-36). Specific observations regarding the distribution of lead in the RYSR and RSAR areas are provided below.

- Lead concentrations in RYSR areas range from 0.37 to 20,500 mg/kg (Table 7-13). The great majority of residential yards within the APSI have lead concentrations that are below screening levels.

Approximately 50 percent of the RYSR samples have lead concentrations that exceed background, 13 percent of concentrations exceed the provisional RSL, and 4 percent exceed the residential RSL. Concentrations in RSAR areas were much lower, as discussed in Section 7.3.3.

- Like arsenic, elevated lead concentrations occur in yards that overlap Upper (NR3) and Middle (NR6) Chaparral Gulch, consistent with the deposition of tailings-impacted sediment in this area and residuals from the MTP Blow Out. In addition, elevated lead concentrations occur along, and adjacent to, the former Smelter Rail Spur.
- The overall distribution of the area with lead above the background concentration of approximately 35 mg/kg is larger and more widespread than that for arsenic. There are some exceptions where lead contamination does not coincide with arsenic contamination. The specific details of these identified exceptions, and clusters of samples with lead concentrations that exceed the screening levels locally at specific yards where the surrounding yards have lower concentrations, are provided in Section 7.3.3 and Table 7-15.

In general, where arsenic or lead concentrations are elevated in shallow soil samples collected off the mine and smelter properties, their concentrations are lower in the collocated deeper samples, which is consistent with aerial deposition of windblown dusts and smelter emissions (Figures 7-7 through 7-10). Exceptions include areas were deeper soil contamination is known to occur, including along the former Smelter Spur, the Tailings Floodplain of Chaparral Gulch, and the confluence of the MTP Blow Out Path and Upper Chaparral Gulch into Middle Chaparral Gulch. Anthropogenic factors such as grading for property development and importing fill for landscaping may have altered distribution of arsenic and lead in the downwind areas. The use of shallow to deep concentration ratios was used to evaluate sitewide fate and transport mechanisms in Section 8. However, it should be noted that other non-site-related contaminant sources such as use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires, could also result in elevated shallow to deep concentration ratios, but elevated concentrations would be expected to be more localized.

7.3.2 Lead and Arsenic – Residential Screening Area Risk Sampling

Eight RSARs were identified, RSAR-A though RSAR-H. Although arsenic or lead concentrations locally (that is, in discrete samples) exceed background or screening levels in the RSAR areas (Figures 7-33 and 7-34), the calculated EPCs for the individual RSAR exposure areas do not exceed the screening levels (Table 7-14), with the exception of a hot spot area identified within the exposure area designated as RSAR-D (Figures 7-33 and 7-34). This hot spot is at the location of a stormwater diversion berm known to be made using imported mine tailings identified as a hot spot during field investigations in 2014. EPCs for this berm were evaluated separately from the remainder of that screening area.

EPCs for arsenic, except in the RSAR-D hot spot, were below the screening level and ranged from approximately 23 to 99 mg/kg (Figure 7-35 and Table 7-14). One of the 19 samples collected in RSAR-H exceeded background and marginally exceeded the screening level for arsenic; however, the arsenic EPC for this area was below background and the screening level. RSAR-H is located on the APSI boundary, northeast of the Site and east of the Agua Fria River (see Figure 6-3 and 7-33). The distance from the Site and low arsenic concentrations in surrounding areas indicates the elevated arsenic is unrelated to Site operations, and is likely a result of varying geologic conditions. All remaining samples in the RSAR sampling areas were below background and the screening level for arsenic.

For lead, calculated EPCs range from 22 to 54 mg/kg (Table 7-14). Lead EPCs exceed the background threshold concentration in RSAR-A, RSAR-B, RSAR-D, and RSAR-H, but not screening levels. The lead EPCs for the remaining RSARs are less than or equal to the lead background concentration of 34.8 mg/kg (Figure 7-36 and Table 7-14). No samples exceeded the residential RSL of 400 mg/kg for lead.

These findings indicate that the only significant site-related impact to RSAR was the construction of the stormwater diversion berm using imported mine tailings in RSAR-D. Lead and zinc concentrations exceed background in some samples from the RSAR areas, and the areas are within or adjacent to the APSI, indicating that the properties may have been subject to windblown tailings or historical Humboldt Smelter stack emissions. However, the degree of impact, and any potentially associated health risk is low, as evidenced by the overall distribution of the COIs compared to concentrations closer to the source areas and the calculated EPCs for the screening areas being below screening levels.

7.3.3 Lead and Arsenic – Residential Yard-Specific Risk Sampling

The majority of residential yards within the APSI have metals concentrations that are below screening levels. As indicated in Table 7-13, arsenic and lead are the most prevalent metals in RYSR areas with concentrations exceeding respective screening levels. A total of 384 yards were sampled as part of RYSR area investigations, inclusive of yards that were combined for sampling. EPCs for arsenic ranged from approximately 11 to 778 mg/kg (Table 7-15). Of the 384 yards, 19 yards have EPCs for arsenic that exceed the screening level (Figure 7-35) and 56 of the yards have EPCs for arsenic that exceed the background level. The EPCs for lead range from approximately 8 to 18,699 mg/kg; 28 yards have EPCs that exceed the residential RSL of 400 mg/kg, 90 yards have EPCs that exceed the provisional RSL of 140 mg/kg, and 298 of the yards have EPCs that exceed background (Figure 7-36 and Table 7-15).

As discussed in Section 7.3.1, many of the yards with the highest lead and arsenic EPCs are located directly north (downwind) of the former Humboldt Smelter property in Humboldt Proper, along the historic Smelter Spur, and in areas of deposition along Chaparral Gulch. Elevated concentrations are primarily limited to the surface. Yards with elevated lead EPCs above screening levels are more prevalent in areas near the smelter as compared with areas farther from the smelter and along the APSI (for example, RSAR areas). This lends some support to the conceptual model of a residual footprint of contamination from historical smelter stack emissions due north of the smelter. However, as discussed in detail in Section 8, development of the area near the former Iron King Mine and Humboldt Smelter properties since operations began has resulted in the redistribution of contamination. This redistribution, in combination with non-site-related sources of elevated metals, has resulted in a more complex patchwork distribution of metals. Hot spots of high lead and/or arsenic concentrations occur in residential yards that are removed from the former mine and smelter properties and surrounded by areas of low concentrations, and there are yards immediately adjacent to the former smelter that contain low EPCs.

A hot spot assessment was performed by ERT to assist with determining the nature of the contamination for some of the parcels that significantly exceed screening levels for arsenic and lead using the following criteria:

- Sampling in the parcel was not sufficiently delineated, and/or
- Contamination was not characteristic of mine waste distribution, and/or
- The parcel was not remediated in the past

Details of the hot spot assessment performed by ERT can be found in Section 11 of the ERT report (included as Appendix F in this RI Report). Most of the parcels identified for assessment contained a hot spot of contamination that drove the EPC to exceed the screening levels.

Table 7-15 summarizes information from the hot spot assessment and additional observations made in the field by EPA or ERT that explain the reason for elevated concentrations. Some of the reasons for hot spots include the following:

- Tailings and mine waste were used as fill.

- Fill was imported from quarries with naturally elevated concentrations of arsenic.

- Construction activities (for example, grading, excavation, or cut-and-fill) exposed rock outcrops or soil with high naturally occurring lead or arsenic. Examples include properties east of the Agua Fria River (for example, yard 1903) and south of the former smelter property in the Maggy Trail residential area (for example, yards 3004 and 3005).
- A small pile of fine-grained grayish soil (or powder) with highly elevated arsenic and lead concentrations was identified on one property on Wells Street. Discovery of this material resulted in EPA performing the accelerated residential sampling in August 2013 of multiple yards near the intersection of Jones and Wells Streets (Lockheed Martin SERAS, 2013c; included in Appendix D).
- Use of leaded gasoline, presence of lead-based paint, or soldering operations have resulted in non-site-related sources of lead contamination.
- A house or building fire has occurred (for example, Yards 2529 and 2602).

7.3.4 Other COIs

As indicated in Table 7-13, other COIs sporadically exceed screening levels in the RSAR and RYSR exposure areas. A detailed listing of the screening-level comparisons for each individual property is provided in Appendix J (Table J-2). Of the 384 yards sampled as part of RYSR area investigations, metals other than arsenic and lead that were found exceeding screening levels in surface soil included cobalt (at 67 properties), iron (at 91 properties), manganese (at 90 properties), and thallium (at 28 properties). Screening levels were exceeded for a smaller number of properties for aluminum (at 1 property), antimony (at 8 properties), copper (5 properties), and mercury (at 1 property). Although some of these COIs may be site-related, in particular copper and zinc, it should be recognized that a number of the COIs are related to the naturally mineralized conditions prevalent in the region, rather than specifically from mine- or smelter-related sources. The distribution of the other COIs is discussed in Section 7.1.1.4 and the potential risk of these metals is detailed in Section 9.

7.4 Sediment

The following sections summarize the nature and extent of contamination in sediment across the Site. This discussion focuses on the lateral distribution of the primary COIs that were found to be representative of the sediment contamination sitewide: arsenic, copper, lead, mercury, and zinc (see Section 6.4). The relative concentrations of the primary COIs and their distribution in sediment are illustrated on Figures 7-37 through 7-41.

Three surface water features transect the Site: the Agua Fria River, Chaparral Gulch, and Galena Gulch. As discussed in detail in Section 10, the Agua Fria River is the only true aquatic habitat in the APSI. The Chaparral Gulch and Galena Gulch are intermittent drainages, and are not covered with water for a sufficient amount of time to support aquatic or benthic organism habitat.

This section discusses all samples historically identified as sediment (whether transitory or permanent), including those samples collected from intermittent surface water features, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways on or near the former Iron King Mine and former Humboldt Smelter properties. Many of these samples were therefore located in areas more indicative of terrestrial habitat, rather than aquatic or benthic organism habitat. However, as discussed in Section 6.3.2, sample results were screened against criteria for the protection of benthic organisms as a conservative approach. Screening levels were used solely to evaluate the nature and extent of contamination; they are not intended to infer the existence of unacceptable risk. Rather, the risk assessments summarized in Sections 9 and 10 provide site-specific estimates of risk. Table 6-3 summarizes the COI exceedances in sediment on a sitewide basis. Table 7-16 includes the analytical results for the COI(s) in sediment samples, including arsenic, lead, other metals, and dioxins/furans (see Section 6.4).

Surface sediment samples (depths of 0 to 2 feet bgs) were collected at most locations. Subsurface samples were collected at two locations in the Tailings Floodplain (NR8) at depths up to 8 feet and in Lower Chaparral Gulch at depths up to 5 feet bgs.

As discussed below in more detail, sitewide primary COIs with the lowest concentrations were detected in upstream reaches of the Agua Fria River, Chaparral Gulch, and Galena Gulch. The maximum concentrations of arsenic, lead, mercury, and zinc were detected in former Iron King Mine property source areas. The highest concentrations of copper were detected in, and adjacent to, former Humboldt Smelter property source areas (specifically NR11, the former Pyrometallurgical Operations area). Concentrations of the primary COIs exceeded screening levels in most of the samples collected from the former Iron King Mine and Humboldt Smelter property source areas and downstream portions of Galena Gulch and Chaparral Gulch. Concentrations also exceeded screening levels in the Agua Fria River, primarily in locations near former Humboldt Smelter property source areas and the confluence with Chaparral Gulch.

7.4.1 Upstream Reaches

Upstream reaches of Galena Gulch, Chaparral Gulch, and the Agua Fria River were sampled in September 2008 as part of the initial phase of the RI; these samples were described as “BKG” or “background” locations (EA, 2010). Samples that were collected upstream of the former Iron King Mine property boundary in Chaparral Gulch and Galena Gulch or upstream of the drainage ditch emanating from the former Humboldt Smelter property in the Agua Fria River are identified as “upstream” for each of the samples listed in Table 7-16. Although these were classified as “background’ locations, a waste rock pile was identified during the data gap phase of the RI (Lockheed Martin SERAS, 2015) located west of the former Mineworks area in the vicinity of the upstream (BKG) Galena Gulch locations. Although the extent of waste rock in this area is small, there is a potential for the waste rock to impact concentrations in this area and affect the estimates of background concentration.

Mercury and lead concentrations were below screening levels in all upstream samples, and zinc only exceeded screening levels in two BKG samples from Galena Gulch. In contrast, arsenic concentrations exceeded the screening level of 9.79 mg/kg in upstream samples from Galena Gulch and Chaparral Gulch, and the majority of upstream samples from Agua Fria River. Copper concentrations exceeded the screening level of 31.6 mg/kg in all BKG samples from Galena Gulch, four of the BKG samples from Agua Fria River, and one of the BKG samples from Chaparral Gulch.

Arsenic is commonly found in the volcanic rocks of the region. Background concentrations were not established for sediment in the *Soil Background Study Report* (CH2M, 2015; included in Appendix E). However, soil background estimates for arsenic and copper were significantly higher than the sediment screening levels listed above. Estimated UTLs of soil background concentrations were calculated as 112 mg/kg for arsenic, 182 mg/kg for copper, 34.8 mg/kg for lead, and 136 mg/kg for zinc. The upstream sediment sample locations and established soil background concentrations are used qualitatively below when evaluating sitewide sediment concentrations.

7.4.2 Former Iron King Mine Property: Operation and Source Areas

Samples designated as sediment were collected from source areas at the former Iron King Mine property, specifically at the MTP (NR17) and the NAI Operations area (NR18). Samples within the area north of the MTP (NR19) were primarily collected adjacent to Chaparral Gulch, or from drainages discharging to Chaparral Gulch; therefore, NR19 sediment samples are discussed with other Chaparral Gulch samples in Section 7.4.5 below. The majority of the samples in NR17 and NR18 were collected in August and September 2008 when standing water was present. Within NR17, samples were collected from the retention ponds on top of, and at the base of, the MTP and ancillary drainage pathways. Within NR18, samples were collected from retention ponds within the NAI Operations area (NR18), which collect stormwater flow around the structures as well as contain overflow from the MTP (EA, 2010). Samples from both areas were designated as sediment and are evaluated here as such, but samples could be considered surface soil during most of the year when there is an absence of surface water (EA, 2010).

The metals concentrations in sediment samples within these former Iron King Mine property source areas are consistent with the surrounding tailings material and contain some of the highest concentrations of arsenic, lead, mercury, and zinc detected sitewide in samples designated as sediment. All sediment samples within the NR17 and NR18 exposure areas exceeded screening levels for all primary COIs. Arsenic concentrations within the NR17 and NR18 exposure areas ranged from approximately 156 to 6,920 mg/kg, copper concentrations ranged from 45 to 551 mg/kg, lead concentrations ranged from 186 to 10,500 mg/kg, mercury concentrations ranged from 0.52 to 49 mg/kg, and zinc concentrations ranged from 510 to 14,400 mg/kg.

7.4.3 Galena Gulch

Galena Gulch transects the southwestern portion of the former Iron King Mine property, adjacent to the former Mineworks area and the former Fertilizer Plant area, and flows south-southeast toward the Agua Fria River. Concentrations of the primary COIs in sediment were greatest on the back slope of the former Fertilizer Plant area. Abandoned mine shafts and areas of waste rock are present on bedrock benches and adjoining slopes along Galena Gulch in the area south of the former Fertilizer Plant (Figure 2-1; Section 4 of Lockheed Martin SERAS, 2015). Many of the sediment samples with elevated concentrations of arsenic and lead were described as tailings material during the initial phase of the RI (EA, 2010). The maximum sitewide sediment concentration of lead (14,300 mg/kg) was detected in this area (location IKJ-566). Maximum concentrations of other primary COIs included 2,800 mg/kg arsenic (IKJ-557), 865 mg/kg copper (IKJ-566), 9.1 mg/kg mercury (IKJ-559), and 6,060 mg/kg zinc (IKJ-565) (Table 7-16).

Most of the downgradient channel of Galena Gulch is largely devoid of sediment, as it lies on the surface of scoured bedrock (CH2M, 2013). Concentrations in sediment samples decrease significantly downgradient in the Galena Gulch; however, concentrations remain above screening levels even in the downgradient samples. COI concentrations in the furthest downstream sediment sample location (GG-14), located just downstream of Highway 69, were 123 mg/kg arsenic, 109 mg/kg copper, 123 mg/kg lead, 0.22 mg/kg mercury, and 502 mg/kg zinc compared to samples collected just downgradient of the former Fertilizer Plant area previously discussed (Table 7-16).

7.4.4 Former Humboldt Smelter Property: Operation and Source Areas

Samples designated as sediment were collected within, and adjacent to, the former Humboldt Smelter property source areas, specifically the former Pyrometallurgical Operations area (NR11) and the Agua Fria Tailings Pile (NR10). The Tailings Floodplain (NR8) is within the former Humboldt Smelter property boundary, but is discussed in the overall context of the Chaparral Gulch system in Section 7.4.5.

7.4.4.1 NR11 Former Pyrometallurgical Operations Area and Adjacent Areas

Samples designated as sediment were collected from a historical surface water retention pond within NR11 (locations HSJ-575, HSJ576, and IP-19 to IP-21) and along the surface water drainage pathway from NR11 to the Agua Fria River (locations HSJ-568 to HSJ-574 and OW-34 through OW-38) (see Figure 7-37). Samples also were collected adjacent to the Agua Fria River and slag piles near the northeastern boundary of NR11 (locations OW-20 and OW-21). Data for these samples are presented in Table 7-16 under sample area “Humboldt Smelter” for the majority of locations, and “Humboldt Smelter/Agua Fria River” for locations along the drainage pathway or bordering the primary slag pile.

The retention pond is located to the northwest of the former Pyrometallurgical Operations area and dross areas. During the initial phase of the RI, the retention pond was observed to be dry, and material at the bottom of the pond resembled “ash” or dross (EA, 2010). The retention pond was likely a component of the dross processing operation and was constructed in the late 1950s or early 1960s (see Section 2.1.3). The primary COIs exceeded screening levels in the majority of the samples collected from the retention pond. The maximum lead concentration of 1,110 mg/kg demonstrates that the material in the retention pond is similar to the source material near the smelter. The maximum arsenic concentration in these samples was 76 mg/kg, copper was 6,960 mg/kg, mercury was 0.9 mg/kg, and zinc was 6,320 mg/kg (Table 7-16).

Concentrations of the primary COIs in samples collected along the current and historical surface water migration pathway were generally higher in locations near the Humboldt Smelter retention pond (HSJ sample locations) compared with downgradient locations in the unnamed wash to the Agua Fria River (OW-34 through OW-38) (Figures 7-37 through 7-41).

Two samples designated as sediment were collected adjacent to the Agua Fria River near the eastern boundary of NR11 (locations OW-20 and OW-21). These samples were collected in an area where EPA observations indicate dross mixed with slag extends down to the Agua Fria River (see Appendix A). The concentrations of COIs exceeded screening levels; the maximum copper concentration detected in sediment was at OW-20 (8,030 mg/kg). The very high aluminum concentrations (110,000 and 52,800 mg/kg in OW-20 and OW-21, respectively), moderate arsenic concentrations (163 and 181 mg/kg), and moderate iron concentrations (29,100 and 24,500 mg/kg) are more characteristic of the dross than slag materials (compare Table 7-16 with Tables 7-11 and 7-12).

7.4.4.2 NR10 Agua Fria Tailings Pile

The Agua Fria Tailings Pile (NR10) contains a localized area of tailings that were likely tremied or slurried from predecessor mining and milling operations occurring in the late 1800s (see Sections 2.1 and 2.3). The Agua Fria Ore Mill and Smelter location is thought to have overlapped the location of the current Agua Fria Tailings Pile (see Figure 2-2). The smelter was supplied ore from the Silver Belt Mine located about 5,500 feet southwest of Iron King Mine, and the Chaparral Gulch Shaft located on the Smelter Plateau. The Silver Belt Mine ore was reported to be mainly oxidized, and contained much silver and some lead (USGS, 1958).

The tailings are located on the northwest bank of the Agua Fria River, upstream of the confluence with Chaparral Gulch. The exposure area extends into the 100-year floodplain of the Agua Fria River. Concentrations of lead and arsenic exceed screening levels in soil within the Agua Fria Tailings Pile exposure area (see Section 7.2.2). One sample collected from NR10 was designated as sediment (OW-18) (see Figure 7-37; included under sample area “Humboldt Smelter” in Table 7-16). Concentrations of all primary COIs exceeded screening levels in this sediment sample and were within the range of concentrations measured in source materials. Arsenic was detected at 1,510 mg/kg, lead was 7,340 mg/kg, mercury at 37.9 mg/kg, and zinc at 3,190 mg/kg. The copper concentration was low for this sediment sample.

7.4.5 Chaparral Gulch

Chaparral Gulch sediment sample locations were grouped into three areas for the purpose of this discussion: (1) areas upstream of the Tailings Floodplain, (2) the Tailings Floodplain and NR8, and (3) Lower Chaparral Gulch. The discussion of Chaparral Gulch includes samples designated as sediment that were collected from the main channel, as well as adjoining drainage channels and outfalls. Concentrations of the primary COIs exceeded screening levels in much of Chaparral Gulch and were greatest in the area of the Tailings Floodplain and Chaparral Gulch Dam.

7.4.5.1 Upstream of the Tailings Floodplain

The section discusses samples designated as sediment that were collected from Chaparral Gulch and associated drainage channels, outfalls, and washes upstream of the Tailings Floodplain. This includes Chaparral Gulch upstream of Highway 69 (exposure areas NR15, portions of NR19 immediately adjacent to the Chaparral Gulch drainage channel, and NR20), Upper Chaparral Gulch (NR3), the MTP 1964 Blow Out Path (NR4 and NR5), and Middle Chaparral Gulch (NR6) (see Figure 6-3 for exposure areas). These areas were potentially impacted by discharges of mine water with high particulate loads during historical Iron King Mine operations and the MTP 1964 Blow Out, and runoff from the MTP, NAI Operations area, and Small Tailings Pile (prior to removal in 2011) (see Figure 2-1).

Concentrations of inorganic COIs generally increase moving from upstream to downstream areas in the portions of Chaparral Gulch mentioned above, demonstrating that impacted sedimentary material has been mobilized from Iron King Mine sources and has collected in the portions of Chaparral Gulch further downstream. Tailings are present within Upper and Middle Chaparral Gulch and the associated drainage and floodplain areas between the mine and the smelter.

As discussed in Section 7.4.1, concentrations of the primary COIs were generally below screening levels upgradient of the Iron King Mine property, with the exception of arsenic. Arsenic concentrations exceeded screening levels in all of the samples collected upgradient of the Iron King Mine property (samples with BKG designation) at concentrations up to 49 mg/kg. The BKG sediment data, in combination with the sitewide soil background UTL of 112 mg/kg, indicate there are naturally occurring sources of arsenic at concentrations exceeding screening levels.

Between the upgradient border of the Iron King Mine property and Highway 69, concentrations of the primary COIs were below screening levels in some of the samples within the main channel of Chaparral Gulch, but were above screening levels in all samples collected from surface water drainage pathways from the Iron King Mine property and in the samples collected near the culvert that allows surface water to pass under Highway 69 (locations CG-9 and OW-7).

Downgradient of Highway 69, concentrations of arsenic, copper, lead, and zinc exceeded screening levels in all samples within the main channel of Chaparral Gulch and within the MTP Blow Out Path, and mercury concentrations exceeded screening levels in the majority of samples.

The maximum concentrations of the primary COIs in samples designated as Chaparral Gulch upstream of the Tailings Floodplain were detected in the following locations:

- North of the Iron King Mine MTP and NAI Operations area, and downgradient of the former Small Tailings Pile (NR19) (location IK-D12)
- Near the culvert that allows surface water to pass under Highway 69 (locations CG-9 and OW-7)
- Upper Chaparral Gulch, just downstream of Highway 69 (NR3) (location CG-10)
- MTP Blow Out Path (NR4 and NR5) (locations CG-1 and CG-11)
- Middle Chaparral Gulch (location IK-D10)

The maximum total concentrations detected in these exposure areas were: arsenic at 509 mg/kg (IK-D12), copper at 388 mg/kg (IK-D10), lead at 522 mg/kg (CG-1), mercury at 2.9 mg/kg (IK-D10), and zinc at 935 mg/kg (CG-10).

7.4.5.2 Tailings Floodplain

Samples designated as sediment were collected in the Tailings Floodplain (NR8) (see Figure 6-3 and Figures 7-38 through 7-41). Impoundment failures and historical discharges from both the former Iron King Mine and Humboldt Smelter properties have released tailings into Chaparral Gulch, forming the Tailings Floodplain (see Sections 2.1.3.6 and 7.2.3). The Chaparral Gulch Dam impounds tailings and native alluvial deposits in the Tailings Floodplain, with a saturated thickness exceeding 20 feet in the area of the dam.

Concentrations of the primary COIs exceeded screening levels in the majority of locations sampled within the Tailings Floodplain. Concentrations of the primary COIs were greater in the Tailings Floodplain than in the Middle or Upper Chaparral Gulch (Figures 7-37 and 7-38, Table 7-16), which confirms the tailings that have accumulated in the floodplain are a significant repository of impacted material. Maximum concentrations detected in the samples were as follows:

- Arsenic at 2,320 mg/kg (location HS-38)
- Copper at 1,340 mg/kg (location HSJ-535)
- Lead at 2,460 mg/kg (location HSJ-534)
- Mercury at 19.5 mg/kg (location HSJ-548)
- Zinc at 3,730 mg/kg (location HSJ-582)

The average concentrations of the primary COIs detected in sediment in NR8 were similar to the average concentrations of soil samples collected within the Tailings Floodplain (discussed in Section 7.2.3.5). Sediment samples were collected at depths up to 8 feet at location CG-22, just upstream of the dam, with maximum concentrations of metals detected in the deepest sample (see Table 7-16).

Dioxins/furans were analyzed in five sediment samples collected in exposure area NR8 in September 2008 (see Table 7-16). Dioxins/furans were detected at all but one location at concentrations exceeding screening levels. The source of these dioxins/furans is unknown; it may be associated with smelting activities (although recent studies indicate that copper smelters have negligible dioxin emissions [Secor International Inc., 1995a, 1995b]), an upstream source in the Chaparral Gulch watershed, or aerial deposition from other sources. The dioxin/furan exceedances are collocated with exceedances of the primary COIs.

7.4.5.3 Lower Chaparral Gulch

Samples designated as sediment were collected in Lower Chaparral Gulch (NR9) (see Figure 6-3 and Figures 7-38 through 7-41). Lower Chaparral Gulch (NR9) is located downstream of the Tailings Floodplain and Chaparral Gulch Dam, and extends to the confluence with the Agua Fria River. Groundwater within the Tailings Floodplain deposits behind the dam seeps beneath or around the dam abutments, providing a low but continuous surface water flow to Lower Chaparral Gulch, and sustaining riparian habitat in this reach (see Section 5.6). Tailings deposits are visible in the Lower Chaparral Gulch canyon (Figure 2-2), that were either associated with precursor operations at the former Agua Fria Mill or possibly discharges of tailings from upstream smelter operations.

Concentrations of the primary COIs exceeded screening levels in the majority of locations sampled within Lower Chaparral Gulch. Maximum concentrations detected in the samples were as follows:

- Arsenic at 783 mg/kg (location DAM-SED03 at 3 to 3.5 feet)
- Copper at 2,630 mg/kg (location DAM-SED03 at surface)
- Lead at 1,540 mg/kg (location DAM-SED05 at 3 to 3.5 feet)
- Mercury at 11.5 mg/kg (location DAM-SED03 at 3 to 3.5 feet)
- Zinc at 2,510 mg/kg (location CHD-BIOSED01 at surface)

Elevated concentrations of metals were detected in surficial sediment throughout Lower Chaparral Gulch as presented on Figures 7-37 through 7-41. The average concentrations of arsenic and lead in sediment samples from Lower Chaparral Gulch were less than the average concentrations in sediment samples from the Tailings Floodplain (300 mg/kg arsenic in NR9 compared with 450 mg/kg in NR8, and 340 mg/kg lead in NR9 compared to 470 mg/kg lead in NR8); however, the average concentrations of copper and zinc were greater (890 mg/kg copper in NR9 compared to 520 mg/kg in NR8, and 1,360 mg/kg zinc in NR9 compared to 990 mg/kg in NR8).

During Phase 4 of the RI, the depth to bedrock was measured as 4.2 feet at the base of the dam (DAM-SED01), 3.5 to 4.5 feet at distances of 250 to 600 feet downstream from the dam (DAM-SED02 to DAM-SED04), greater than 5 feet near the Lower Chaparral Gulch tailings deposit at the "elbow" where Chaparral Gulch turns north (DAM-SED05), and 0.5 to 2.0 feet further downstream (DAM-SED06 to DAM-SED08) (Lockheed Martin SERAS, 2015). Elevated metals concentrations were detected in all subsurface sediment samples in Lower Chaparral Gulch, and in most cases, the maximum concentration with depth was detected in the middle or deepest samples (see Table 7-16). Figures 7-37 through 7-41 show the maximum concentration detected at each location. The Lower Chaparral Gulch tailings deposit near DAM-SED05 is likely associated with precursor operations; however, the distribution of sediment with elevated concentrations throughout Lower Chaparral Gulch indicates wastes likely also migrated to this downstream reach of the gulch from upstream sources.

7.4.6 Agua Fria River

Sediment samples were collected within or adjacent to the following portions of the Agua Fria River (see Figures 7-37 through 7-41):

- Upstream reach thought to constitute background conditions (locations BKG-AF-1 thru BKG-AF-10) (EA, 2010)
- Adjacent to Humboldt Smelter source area NR11 (locations OW-20, OW-21, and OW-34 through OW-38; see Section 7.4.4 for further discussion)
- Agua Fria River within the APSI but upstream of the confluence with Chaparral Gulch
- Agua Fria River downstream of the confluence with Chaparral Gulch

As discussed in Section 7.4.1, concentrations of the primary COIs were generally below screening levels in the upgradient Agua Fria River locations, with the exception of arsenic and copper (see Figures 7-37 through 7-41). Arsenic concentrations exceeded the screening level in 60 percent of the upstream Agua Fria River samples with detections up to 41 mg/kg, while copper exceeded the screening level in 40 percent of the samples with detections up to 46 mg/kg (Table 7-16). The upgradient data, along with the sitewide soil background UTLs of 112 mg/kg for arsenic and 182 mg/kg for copper, indicate there are naturally occurring sources of arsenic and copper at concentrations exceeding screening levels.

The primary COIs were detected in sediment samples collected adjacent to the Humboldt Smelter source area NR11 at concentrations exceeding screening levels. The greatest concentrations were detected at locations OW-20, OW-21, and OW-34 through OW-38, which are discussed in context with the Humboldt Smelter source areas in Section 7.4.4. Otherwise, concentrations of lead, mercury, and zinc were below screening levels upgradient of the confluence of Chaparral Gulch in all but one sample (location AF-5). Arsenic and copper exceeded screening levels in numerous samples; however, samples with concentrations above 55 mg/kg were limited to AG-BIOSED04 (127 mg/kg arsenic) and AF-5 (1,140 mg/kg copper). Both AG-BIOSED04 and AF-5 are located adjacent to exposure area NR11.

Dioxins/furans were analyzed in five sediment samples collected in the Agua Fria River adjacent to Humboldt Smelter source areas in May 2014 (locations AG-BIOSED01 through AG-BIOSED05) (Table 7-16). No dioxins/furans were detected at locations AG-BIOSED04 or AG-BIOSED05, and detections at AG-BIOSED03 were below screening levels. Dioxins/furans were detected at concentrations exceeding screening levels at location AG-BIOSED01, which is at the outfall of the surface water drainage pathway from NR11. The OCDD congener exceeded the screening level at AG-BIOSED02, which is adjacent to exposure area NR11; other congeners (1,2,3,4,6,7,8-HeptaCDD; 1,2,3,4,6,7,8-HeptaCDF; and OCDF) were nondetect at this location. All data were J-flagged, indicating the concentrations are approximate. The dioxin/furan screening level exceedances are likely associated with the dross material, based on the distribution of exceedances.

Chaparral Gulch is a source of impacted material to the Agua Fria River, as shown by the increase in concentrations of the primary COIs downgradient of the confluence. Erosion of material from the Agua Fria Tailings Pile and historical impacts from predecessor operations at the former Agua Fria Mill (Figure 2-2) are other possible sources of impacted sediment in the Agua Fria River near or downstream of the confluence with Chaparral Gulch. The maximum concentrations of the primary COIs downstream of the Chaparral Gulch confluence were detected at location AF-12, sampled in August 2008. Arsenic was detected at 206 mg/kg, copper at 423 mg/kg, lead at 361 mg/kg, mercury at 1.2 mg/kg, and zinc at 1,060 mg/kg. This location was resampled to confirm the results during a subsequent field effort, and concentrations were lower by an order of magnitude in the resample. For example, the arsenic concentration was 26.9 mg/kg in April 2009 (sample AF-13) and 17 mg/kg in May 2014 (sample AG-BIOSED10). This demonstrates that impacts to this stretch of the Agua Fria River are localized, the sediment material in this area is transient, or a combination of both factors (EA, 2010).

Concentrations of the primary COIs were either below screening levels or marginally exceeded screening levels (concentrations were less than 1.5 times screening levels) in the farthest downstream locations sampled in May 2009 (locations AF-17 and AF-18) (Figures 7-37 through 7-41).

7.5 Surface Water

This section summarizes the distribution of the primary COIs representative of the sitewide impacts to surface water: arsenic, copper, iron, lead, and zinc (see Section 6.4). Sulfate was also evaluated as an indicator of mining-related impacts (for example, ARD). The relative concentrations of these constituents and their distribution in surface water are illustrated on Figures 7-42 through 7-47. Tables 7-17 and 7-18 summarize surface water analytical data and the COI exceedances for total and dissolved fractions, respectively.

Three surface water features transect the Site: the Agua Fria River, Chaparral Gulch, and Galena Gulch. The Agua Fria River is the primary surface water feature in the valley and provides the only true aquatic habitat that occurs within the boundaries of the Site. This section discusses all samples historically identified as surface water samples (whether transitory or permanent), including samples collected from intermittent surface water features, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways on or near the Humboldt Smelter and Iron King Mine sites.

Samples were screened against water quality goals for the protection of aquatic life as a conservative approach. Screening levels were used solely to evaluate the nature and extent of contamination; they are not intended to infer the existence of unacceptable risk. Rather, the risk assessments summarized in Sections 9 and 10 provide site-specific estimates of risk. For water quality goals that vary with hardness, a conservative assumption of a default hardness of 100 mg/L as $CaCO_3$ was assumed for this screening-level assessment. A more detailed evaluation using site-specific hardness values for the Agua Fria River was conducted in the risk assessment in Section 10. As a conservative approach for identifying COIs and for the nature and extent evaluation, water quality goals for dissolved metals concentrations were converted to goals for total metals if screening levels for total metals were not available. Table 6-4 summarizes the COI exceedances in surface water on a sitewide basis.

Surface water samples presented on Figures 7-42 through 7-47 and summarized in Tables 7-17 and 7-18 were collected during the following investigations and times of year:

- January 2004 as part of the PA/SI of the former Humboldt Smelter (ADEQ, 2004)
- March 2008 as part of the Ironite Products Company/NAI sampling (Brown and Caldwell, 2009b)
- August and September 2008, and April and May 2009 as part of the Initial RI (EA, 2010)
- May, July, August, and October 2014 as part of the ERT Data Gap RI (Lockheed Martin SERAS, 2015)

As discussed in Section 5.2, precipitation occurs throughout the year, with approximately 40 percent of the annual total in July and August when monsoonal thunderstorms are common.

Concentrations of the primary COIs exceeded screening levels in much of Chaparral Gulch and Galena Gulch, and were higher in downstream reaches of these streams due to site-related impacts. The highest concentrations of COIs were detected in surface water on top of, and at the base of, the MTP; in Chaparral Gulch downstream of Iron King Mine; and in the area of the Tailings Floodplain and Chaparral Gulch Dam. Site-related contamination in the Agua Fria River was limited to locations near the Humboldt Smelter slag pile and at, and immediately downstream of, the confluence with Chaparral Gulch.

Although background concentrations in surface water have not been formally determined, concentrations of some metals exceed the screening levels in a large number of samples and have comparable concentrations both upstream and downstream of the Iron King Mine and Humboldt Smelter source areas, suggesting potential for elevated concentrations in ambient water quality. As an example, 95 percent of samples exceed screening levels for barium, including all samples collected from upstream reaches of the Agua Fria River. Most of the flow in the Agua Fria River upstream of the Town of Dewey-Humboldt consists of effluent from the Prescott Valley Wastewater Treatment Plant (ADEQ, 2009). In addition, there are upstream agricultural uses (see Figure 5-16A), and local geology results in elevated mineralization in soils and alluvial materials eroded from these areas.

7.5.1 Former Iron King Mine Property: Operation and Source Areas

Maximum sitewide concentrations of arsenic, iron, zinc, and sulfate in surface water were detected in samples collected from the retention ponds on top of, and at the base of, the Iron King Mine MTP (exposure area NR17) (locations IP-1 to IP-9 and SW-1). Samples IP-1 to IP-9 were collected in August and September 2008 when standing water was present. Samples SW-1 and SW-2 (located in the NAI Operations Area) were collected in March 2008 and were only analyzed for total arsenic and lead (Brown and Caldwell, 2009b). COIs exceeded screening levels in most of the samples (Figures 7-42 through 7-46). Total and dissolved concentrations were similar in these samples, where analyzed, and pH was low (for example, the pH was 2.5 in IP-1). Maximum concentrations detected in the samples were as follows (see Tables 7-17 and 7-18):

- Total and dissolved arsenic at 198 and 205 mg/L, respectively (locations SW-1 and IP-9)
- Total and dissolved copper at 47 and 45 mg/L, respectively (location IP-9)
- Total and dissolved iron at 13,000 and 11,900 mg/L, respectively (location IP-9)
- Total and dissolved lead at 1.54 and 0.885 mg/L, respectively (locations SW-1 and IP-3, respectively)
- Total and dissolved zinc at 1,610 and 1,740 mg/L, respectively (locations IP-2 and IP-9)
- Sulfate at 27,000 mg/L (location IP-1)

Standing water was also sampled in September 2008 from three retention ponds in the NAI Operations area (NR18) (locations IP-10 to IP-12 and SW-2). These ponds retain stormwater flow within and around the NAI buildings, as well as contain overflow from the MTP (EA, 2010). Additionally, one surface water sample (SW-2) was collected in March 2008 and analyzed for total arsenic and lead (Brown and Caldwell, 2009b). Concentrations at these locations were much lower than at the MTP. Arsenic and iron concentrations were below the surface water screening levels. Total and dissolved copper, total lead, and total and dissolved zinc exceeded screening levels. The pH of these samples was less acidic (for example, pH of 5.5 in IP-11), and the sulfate concentration was lower than the MTP locations (maximum of 1,100 mg/L at IP-11) (Figure 7-47).

7.5.2 Galena Gulch

As discussed for sediment, Galena Gulch transects the southwestern portion of the former Iron King Mine property, adjacent to the former Mineworks area and the former Fertilizer Plant area, and flows south-southeast toward the Agua Fria River. Abandoned mine shafts and areas of waste rock are present on bedrock benches and adjoining slopes along Galena Gulch in the area south of the former Fertilizer Plant (Figure 2-1; Section 4 of Lockheed Martin SERAS, 2015).

Unfiltered surface water samples were collected from three locations in the Galena Gulch drainage in August 2008 during what was reported to be a high rain event (EA, 2010) (Table 7-17). The locations were as follows, from upstream to downstream:

- GG-4: Portion of Galena Gulch running through southwestern corner of former Fertilizer Plant area
- OW-14: Outfall/wash emanating from the southeastern corner of the former Mineworks area
- GG-14: Portion of Galena Gulch just east of Highway 69

Total arsenic was below screening the level in GG-4; otherwise concentrations of the primary COIs exceeded screening levels in all three samples. Concentrations were generally lowest at the furthest upstream sample location (GG-4), and highest in the drainage ditch emanating from the former Mineworks area (OW-14) (Figures 7-42 through 7-46). These data indicate inorganics are mobilized from the former mine property during storm events.

7.5.3 Chaparral Gulch

Chaparral Gulch surface water sample locations were grouped into three areas for the purposes of this discussion: (1) areas upstream of the Tailings Floodplain, (2) the Tailings Floodplain and NR8, and (3) Lower Chaparral Gulch. The discussion of Chaparral Gulch includes samples designated as surface water that were collected from the main channel, as well as adjoining drainage channels and outfalls.

During the ERT investigation, two types of surface water samples were collected: baseline flow samples (collected during baseflow conditions; DAM-SW01 through DAM-SW06), and samples collected during storm events (which were intended to characterize water quality during high intensity rain events; SWD-01 through SWD-09) (see Section 4.5.10). The baseline flow samples were collected in May 2014 below Chaparral Gulch Dam in areas characterized by continuous groundwater seepage. Storm event samples were collected using dedicated sampling devices in Chaparral Gulch upstream, within, and downstream of the Tailings Floodplain, and in the Agua Fria River. Dedicated sampling devices allowed samples to be automatically collected during high intensity rain events without requiring staff to be mobilized to the Site for sampling. Subsequent to rainfall events, with rainfall accumulations typically equal to or greater than 0.5 inch, staff were deployed to the Site at the earliest possible dates (in July, August, and October 2014) to check the dedicated sampling devices at SWD sample locations and retrieve water samples that had been collected (Lockheed Martin SERAS, 2015). For storm sampling events, it was found that some of the devices did not completely fill with water, thus limiting both the number of samples collected and types of analyses that could be performed (especially field measurements).

Tables 9-2 and 8-2 in the ERT report (Lockheed Martin SERAS, 2015) contain surface water field measurements for the baseline flow samples and samples collected during storm events, respectively. For the baseline flow samples, measurements of conductivity, dissolved oxygen, oxidation-reduction potential (ORP), pH, and temperature were obtained (measurements of turbidity were not obtained). Measurements for pH ranged from 6.3 to 8.2, indicating that pH is near neutral. For the samples obtained during storm events, measurements of conductivity, ORP, pH, and turbidity were obtained, when sample volume was available. Measurements for pH continued to be near neutral, ranging from 7.5 to 8.7. The turbidity in sample SWD-05 was 585 nephelometric turbidity units (NTU), while turbidity in the remaining storm event samples (SWD-06, SWD-07, and SWD-08) was greater than 1,000 NTU. High turbidity indicates that these drainages were carrying a large sediment load during the storm events.

Concentrations of the primary COIs exceeded screening levels in much of Chaparral Gulch and were greatest immediately downstream of Iron King Mine and in the area of the Tailings Floodplain and Chaparral Gulch Dam (Figures 7-42 through 7-46). Concentrations of total metals were elevated in storm event samples compared with baseflow samples.

7.5.3.1 Upstream of Tailings Floodplain

Surface water samples were collected from Chaparral Gulch and associated drainage channels, outfalls, and washes upstream of the Tailings Floodplain. This included Chaparral Gulch upstream of Highway 69 (includes exposure areas NR19 and NR20), Upper Chaparral Gulch (NR3), the MTP Blow Out Path (NR4 and NR5), and Middle Chaparral Gulch (NR6) (see Figure 6-3 for exposure areas). These areas were impacted by historical discharges of mine water with high particulate loads, the MTP 1964 Blow Out, and runoff from the MTP, NAI Operations area, and Small Tailings Pile (prior to removal in 2011) (see Figure 2-1).

Total concentrations of inorganic COIs generally increase moving from upstream to downstream areas in the portions of Chaparral Gulch mentioned above (Figures 7-42 through 7-46), demonstrating that impacted sedimentary material has been mobilized from Iron King Mine sources, or that contaminants are being redissolved or resuspended from material already deposited.

The majority of surface water samples in these exposure areas were collected during the monsoon season, in August 2008 (EA, 2010) and July and August 2014 (Lockheed Martin SERAS, 2015). The highest concentrations of the primary COIs were detected in the following sampling locations:

- Near the culvert that allows surface water to pass under Highway 69 (locations CG-9 and SWD-01)
- Main channel of Chaparral Gulch, just downstream of Highway 69 (NR3) (location CG-10)
- MTP Blow Out Path (NR5) (location CG-11)

The maximum total concentrations detected were arsenic at 2.1 mg/L (CG-9), copper at 0.59 mg/L (CG-9), iron at 594 mg/L (CG-10), lead at 10 mg/L (CG-9), and zinc at 27 mg/L (CG-9). The total lead concentration of 10 mg/L was the maximum concentration detected sitewide.

Only one sample in Chaparral Gulch upstream of the Tailings Floodplain was analyzed for dissolved metals: CG-24 in NR20, upstream of Highway 69. Dissolved zinc slightly exceeded the screening level; concentrations of dissolved arsenic, copper, lead, and iron were nondetect or below screening levels.

7.5.3.2 Tailings Floodplain

Surface water samples were collected in the Tailings Floodplain (NR8). Little or no storage capacity remains behind the Chaparral Gulch Dam because of the accumulation of tailings and alluvium, which can now continue to migrate downstream to the Agua Fria River.

During Phase 1 of the RI, water in the Tailings Floodplain was sampled after rain events, when surface water was pooled or flowing slightly toward the dam. During Phase 4 of the RI, dedicated sampling devices were installed at two locations in NR8 to monitor storm flows: SWD-03 (in Chaparral Gulch along the edge of the Smelter Tailings Swale) and SWD-04 (in Chaparral Gulch immediately upstream of the dam). Two baseflow samples (DAM-SW01 and DAM-SW02) were collected at the dam in May 2014 (Lockheed Martin SERAS, 2015), and additional baseflow samples were collected downstream in Lower Chaparral Gulch (as discussed in following section).

Total concentrations of the primary COIs exceeded screening levels in the majority of locations sampled in the Tailings Floodplain (Figures 7-42 through 7-46, and Table 7-17). The maximum concentrations of total arsenic, copper, iron, and zinc were detected in samples collected using the dedicated sampling devices designed to capture storm flows (locations beginning with SWD), and indicate that erosion and entrainment of tailings was occurring. The stormwater sample collected in October 2014 at the edge of the Smelter Tailings Swale (SWD-03) had the highest concentrations of arsenic of 40 mg/L (SWD-03 on October 2, 2014), copper of 400 mg/L (SWD-03 on October 2, 2014), and iron of 6,700 mg/L (SWD-03 on October 2, 2014) detected in NR8. The SWD-03 copper concentration was the maximum detected sitewide and shows the influence of smelter tailings on this storm sample. The stormwater samples collected immediately upstream of the dam (SWD-04) had the highest concentrations of lead (0.67 mg/L at SWD-04 on July 30, 2014) and zinc (400 mg/L at SWD-04 on August 15, 2014) detected in NR8, suggesting influence by Iron King Mine tailings on these samples. The only samples with higher concentrations of zinc were collected from the Iron King Mine retention ponds on the MTP. The stream stage measurements and peak flow events during this time period are described in Section 5.3.2.

In comparison to the storm samples, the maximum total concentrations associated with the baseflow samples (DAM-SW01 and DAM-SW02) collected in May 2014 near the dam were an order of magnitude or more lower and included the following: arsenic at 0.7 mg/L, copper at 0.1 mg/L, iron at 40 mg/L, lead at 0.057 mg/L, and zinc at 1.2 mg/L. Sulfate concentrations were elevated in surface water samples collected from Chaparral Gulch in the Tailings Floodplain and at the dam, and ranged from 1,100 to 2,100 mg/L (Figure 7-47 and Table 7-17), indicating impacts from ARD as discussed further in Section 8.3.4.

The frequency of exceedances of dissolved metals (Table 7-18) was lower than total metals. Dissolved lead was nondetect or below screening levels in all surface water samples in NR8. Lead is not mobile outside of a highly acidic environment, and at the pH range observed in site surface water, is likely to form insoluble oxides. Dissolved arsenic only exceeded screening levels in one sample, CG-14, which was also the location of the maximum concentrations of dissolved copper, iron, and zinc detected in the Tailings Floodplain. This location was 325 feet north of the dam and consisted of stagnant pooled water colored “greenish magenta to lighter orange” with a pH of 2.9 (EA, 2010), all indications that this was an area of ARD generation. Given the low pH, total and dissolved metal concentrations were very similar in this sample. In contrast, the dissolved metal concentrations in the storm event sample collected at the edge of the Smelter Tailings Swale (SWD-03), were much lower than the total concentrations (dissolved copper was detected at a concentration of 3 mg/L at SWD-03 compared with total copper of 25 to 400 mg/L).

7.5.3.3 Lower Chaparral Gulch

Surface water samples were collected from Lower Chaparral Gulch (NR9), which is located downstream of the Tailings Floodplain and Chaparral Gulch Dam and extends to the confluence with the Agua Fria River. Surface water readily flows over the dam, and percolating surface water and groundwater seep from the dam during most of the year.

During Phase 1 of the RI, surface water in Lower Chaparral Gulch was sampled when pooled or flowing slightly downstream of the dam (EA, 2010). During Phase 4, three baseflow samples (DAM-SW03, DAM-SW04, and DAM-SW06) were collected in NR9 in May 2014 (Lockheed Martin SERAS, 2015). Dedicated sampling devices were installed at two locations in NR9 to monitor storm flows: SWD-05 and SWD-07.

Total concentrations of the primary COIs exceeded screening levels in the majority of locations sampled in Lower Chaparral Gulch (Figures 7-42 through 7-46, and Table 7-17). The maximum concentration of total copper was detected in samples collected using the dedicated sampling devices designed to capture storm flows (maximum detection of 124 mg/L at SWD-05, compared with a maximum detection of 2.3 mg/L in baseflow sample DAM-SW03). This indicates continued impacts from entrained smelter tailings. The total concentrations of other metals (arsenic, iron, lead, and zinc) were elevated but similar between storm flow samples and baseflow sample DAM-SW03 downstream of the dam. This could be due to disturbance of sediments during base flow sampling, in particular areas with shallow or low flow. For some metals, this may also be related to the presence (and possible resuspension during sampling) of oxyhydroxide metal precipitates downstream of the dam. Total lead concentrations were generally higher downstream of the dam compared with upstream (maximum of 1.29 mg/L detected downstream of the dam at SWD-05 compared with a maximum of 0.67 mg/L detected upstream of the dam at location SWD-04). It is unknown if the higher total lead concentrations in surface water are due to higher concentrations of metals in sediment/soil or due to more entrained sediment in the samples. There were elevated concentrations of lead (greater than 1,000 mg/kg) downstream of the dam in sediment at depths of 3 feet at DAM-SED03 and DAM-SED05 and in soil samples in the area of the elbow tailings (see Figure 7-25). Efflorescent salts with elevated metals concentrations were observed within and on top of this tailings deposit.

The frequency of exceedances of dissolved metals (Table 7-18) was lower than total metals. Dissolved arsenic concentrations were below the screening level in all surface water samples in NR9, and dissolved lead was nondetect or low (only marginally exceeding the screening level). As discussed for NR8, lead is not mobile outside of a highly acidic environment. The highest concentrations of dissolved copper and iron were detected in the storm event sample collected at SWD-05 (93 and 9 mg/L, respectively), and the highest concentrations of dissolved zinc were detected at SWD-05 and SWD-07 (45 mg/L at both locations). Dissolved metals concentrations for baseflow samples (locations DAM-SW03, DAM-SW04, and DAM-SW06) were below screening levels for all constituents with the exception of barium (which also exceeded screening levels in all upstream samples) and manganese (DAM-SW03 and DAM-SW04 only).

Sulfate and pH data indicate that ARD impacts diminished with distance from the dam. Sulfate concentrations were 1,000 mg/L or greater in samples collected within 450 feet of the dam, with a maximum detection of 2,500 mg/L in the storm event sample collected at SWD-05 (Figure 7-47 and Table 7-17). In contrast, the sulfate concentration was 350 mg/L in the storm event sample collected approximately 650 feet downstream of the dam at SWD-07, and the sulfate concentration was low (53 mg/L) in the baseflow sample collected at the confluence with the Agua Fria River (DAM-SW06). The pH measurements in the baseflow samples consistently increased with distance downstream of the dam, with the lowest pH (6.3) measured just below the dam (DAM-SW01) and the maximum pH of 8.2 measured at the confluence with the Agua Fria River (DAM-SW06) (see Table 9-2 of the ERT Report).

7.5.4 Agua Fria River

Surface water samples were collected in three portions of the Agua Fria River (Figure 7-42):

- Upstream reach classified as background (locations BKG-AF-1 thru BKG-AF-10) (EA, 2010)
- Agua Fria River within the APSI but upstream of the confluence with Chaparral Gulch
- Agua Fria River downstream of the confluence with Chaparral Gulch

The primary COIs were below screening levels in the upstream “background” samples, with the exception of total iron, which slightly exceeded the screening level of 1 mg/L in one sample (BKG-AF-2) (Figure 7-46). Samples were collected from these locations in August and September of 2008.

Total and dissolved arsenic concentrations were below screening levels in all portions of the Agua Fria River (Figure 7-42, Tables 7-17 and 7-18). Concentrations of other metals show that site-related contamination in the Agua Fria River was limited to locations adjacent to the former Pyrometallurgical Operations area (NR11) and at, and immediately downstream of, the confluence with Chaparral Gulch.

Upstream of the confluence with Chaparral Gulch, total copper, iron, lead, and zinc exceeded screening levels at location SWD-08; otherwise concentrations of the primary COIs were below screening levels (Figures 7-43 through 7-46). SWD-08 was one of the locations with a dedicated sampling device used to monitor storm flows (Lockheed Martin SERAS, 2015); the turbidity of the sample was greater than 1,000 NTU, indicating the Agua Fria was carrying a large sediment load during the storm event. Location SWD-08 is adjacent the former Pyrometallurgical Operations area (NR11), near an area of elevated sediment concentrations and where EPA observations indicate loose, crumbling slag and dross extend down to the edge of the Agua Fria River (Photographs 31 and 32 in Appendix A). However, metal concentrations in other surface water samples collected near this location were below screening levels. Because no upstream surface water samples were collected during storm events, it is unclear whether the surface water concentrations detected at SWD-08 are a result of erosion of smelter-impacted materials and/or non-smelter-related sources such as upstream agricultural uses and stormwater runoff.

Concentrations of the primary COIs were elevated at the confluence with Chaparral Gulch compared with concentrations at upstream sampling locations in the Agua Fria River, but were orders of magnitude lower than concentrations detected in Chaparral Gulch (Figures 7-42 through 7-46). Dissolved zinc exceeded the screening level at locations near the confluence, while total and dissolved copper, total iron, total lead, and total zinc exceeded screening levels at locations up to 2,500 feet downstream.

Total and dissolved concentrations of the primary COIs were all below screening levels in the furthest downstream locations sampled in May 2009 (locations AF-17 and AF-18), which are between 3,000 and 3,500 feet from the confluence.

The concentration of sulfate was below 100 mg/L in all samples collected in the Agua Fria River, more than an order of magnitude below concentrations detected in the Tailings Floodplain and Lower Chaparral Gulch (Figure 7-47 and Table 7-17). The maximum sulfate concentration of 96 mg/L was detected at the confluence of the Agua Fria River and Chaparral Gulch. The low sulfate concentrations in the Agua Fria River indicate that the transport of ARD has not significantly impacted the river.

7.6 Groundwater

EPA installed 26 monitoring wells screened in the alluvium (and tailings), Hickey Formation, and Precambrian bedrock (see Section 5.5). Table 5-4 summarizes the well construction details. Table 6-5 summarizes the COI exceedances in groundwater on a sitewide basis. This discussion focuses on the distribution of the primary COIs in groundwater: arsenic, lead, nitrate, sulfate, and TDS.

Tables 7-19 (metals) and 7-20 (other constituents) summarize groundwater analytical data and the COI exceedances for EPA monitoring wells. Tables 7-21 and 7-22 provide the same information for water supply and other wells. Figure 7-48 shows the distribution of arsenic (dissolved), lead (dissolved), nitrate, sulfate, and TDS in groundwater based on the most recent samples collected from each well, the majority of which were from October 2014. Concentrations of individual primary COIs are presented on Figures 7-49 through 7-55.

Numerous domestic supply wells in the vicinity of the Site were sampled during pre-NPL investigations and the initial phase of the RI (EA, 2010). Available analytical data for samples from these wells begins in 2002; the most extensive data were collected between 2008 and 2012, with some of these wells sampled multiple times. In general, documentation regarding the construction details for these wells is not available. Private and public supply wells are constructed to intercept as much water as possible, with well screens that can cross multiple hydrogeologic units and non-isolating annular gravel packs. So while these wells provide information on overall groundwater concentrations, they do not allow unit-specific delineation of groundwater concentrations. Tables 7-21 and 7-22 summarize the analytical results for COIs detected in the supply wells.

From a sitewide perspective, the groundwater data show the following:

- Elevated sulfate concentrations most consistently demarcate groundwater impacted by ARD generation. The area of impact is limited to the shallow groundwater zones beneath and between the mine and smelter properties and along Chaparral Gulch. Sulfate concentrations in the deeper Precambrian bedrock monitoring wells beneath and near the former Iron King Mine and Humboldt Smelter properties are not elevated and the water chemistry signature is distinctly different, indicating a lack of hydraulic communication between the shallow groundwater and the deeper fractured Precambrian basement rocks.
- The groundwater pH is slightly lower in areas where elevated sulfate concentrations occur, but repeatable pH values below 6 were not observed, indicating that residual neutralizing capacity in waste materials and local soils and groundwater matrix minerals are buffering the ARD acidity.

- ARD impacts from metals are more localized than sulfate. Arsenic, lead, and TDS locally exceed screening levels in shallow groundwater underlying and immediately downgradient of the MTP and in the saturated tailings-impacted alluvium impounded upstream of the Chaparral Gulch Dam.
- Groundwater in the vicinity of the Humboldt Smelter is locally impacted by chloride, nitrate, and TDS. These exceedances may be associated with releases of wastewater from dross processing, leaching of exposed dross, or a combination of these processes. The TDS, chloride, and nitrate impacts associated with the Humboldt Smelter site may extend off-property to nearby domestic wells.
- Regional groundwater impacts not related to the Site include elevated arsenic concentrations in public and private supply wells and EPA bedrock monitoring wells that are associated with natural mineral sources in the area, and elevated nitrate and TDS concentrations associated with older septic systems and past agricultural activities.

7.6.1 Former Iron King Mine Property

Groundwater samples were collected at the former Iron King Mine property from wells located in or near the former Mineworks, MTP, and NAI Operations area. Arsenic, lead, sulfate, and TDS exceed screening levels at the former Iron King Mine property.

Maximum sitewide concentrations of arsenic (1.95 mg/L), zinc (14.6 mg/L), and sulfate (4,800 mg/L), along with elevated TDS (7,600 mg/L) were detected at sample locations GW-999954 and the cistern near the former Mineworks on the western edge of the former Iron King Mine property. GW-999954 consists of a PVC casing installed to a depth greater than 3,000 feet bgs in the flooded mine workings in Old Mine Shaft No. 7. The cistern contains water pumped from Old Mine Shaft No. 7, and was sampled when the pump in GW-999954 was inoperable (EA, 2010). The ore zone groundwater from GW-999954 confirms the rich source of trace metals and sulfate, and the potential for oxidation and dissolution of these materials to groundwater. Concentrations observed at these sample locations are much greater and are not considered representative of samples from wells screened in Quaternary alluvium, the Hickey Formation, and the shallower depths of the bedrock, which are the main focus of this work.

The oxidation of the common mineral pyrite (iron sulfide) produces acidic, iron- and sulfate-rich solutions. Sulfate concentrations in groundwater are a useful indicator of ARD impacts because sulfate is more mobile than metals and behaves conservatively in groundwater under most conditions. Elevated sulfate concentrations occur within the flooded underground Iron King Mine workings and in wells completed within the Hickey Formation beneath and downgradient of the MTP. Sulfate concentrations in the Hickey Formation in this area range from 780 mg/L in MW-9D, located near the western (upgradient) end of the MTP, to 2,200 mg/L in MW-07S, located across Highway 69 immediately east (downgradient) of the MTP (Figures 7-48 and 7-54). Samples from the two wells screened in the tailings showed differing sulfate content, with 55 mg/L in MW-08S and 2,400 mg/L for MW-09S. Samples were collected from these two wells in 2012; MW-08S and MW-09S were dry during the 2014 groundwater sampling event that was used as the basis for the other data presented in this section. Given the known high content of sulfate and sulfide minerals present in the tailings, it is likely that the low value in MW-08S represents a dilution from a recent rain event; however, there is no direct evidence for this.

In contrast to the Hickey Formation, sulfate concentrations in the bedrock monitoring wells near Iron King Mine are not elevated, suggesting limited migration of ARD impacts within the fractured bedrock (Figure 7-48). Sulfate impacts associated with the MTP extend downgradient to well GW-999945, where sulfate concentrations have ranged from 1,100 to 1,300 mg/L. To a lesser degree, this impact appears to extend to other wells that trace the path of Chaparral Gulch (MW-10S, GW-999903, and GW-999958), with sulfate concentrations ranging between 220 and 270 mg/L. By comparison, sulfate in off-property locations is consistently below 200 mg/L, and commonly below 100 mg/L (see Section 7.6.4).

TDS concentrations are also elevated at these high-sulfate locations (compare Figures 7-54 and 7-55), although there are some additional TDS values in the town area wells above 500 mg/L that do not contain elevated sulfate. Groundwater pH values in the sulfate-impacted monitoring wells are slightly acidic, with the majority of these samples between pH 6.2 and 7, compared to pH values in wells that do not appear to be impacted by sulfate (a range of about 6.8 to 8.0). Acidic pH values have been reported for the bedrock monitoring wells near Iron King Mine, but these values are not repeatable and are not considered to be representative (Table 7-20). Recent field parameters collected in 2015 show pH values to be consistently near neutral (Table 7-4 of the data gap report [Lockheed Martin SERAS, 2015]).

Impacts from dissolved metals are more localized than sulfate because adsorption and precipitation reactions limit their mobility. The concentrations of arsenic, lead, and other metals are elevated in the flooded underground Iron King Mine workings, but their concentrations are lower in the Hickey Formation beneath the MTP (Figure 7-48). Dissolved lead was found above screening levels in only one sample from the Hickey Formation (0.022 mg/L in the July 2014 sample from MW-08D). A second dissolved lead analysis was performed on a sample from this well, collected in October 2014, and was below the detection limit of 0.000021 mg/L. Given that total lead concentrations are much greater than dissolved lead across the Site, and that lead is both insoluble and strongly adsorbed in the site pH range, it is likely that the July 2014 sample was influenced by suspended colloids.

Arsenic concentrations in the shallow wells immediately downgradient of the MTP (for example, MW-07S) only slightly exceed the MCL, despite elevated sulfate concentrations at these locations (Figure 7-48). In addition, arsenic and lead concentrations have not exceeded MCLs further downgradient in well GW-999945, despite similar sulfate concentrations at that location. Arsenic concentrations exceed the MCL in all EPA bedrock monitoring wells (Figure 7-48), but the exceedances appear to be related to ambient groundwater conditions rather than ARD, as sulfate concentrations are relatively low in the bedrock wells. The bedrock wells also have a consistently different general chemical signature: sodium- or calcium-bicarbonate, compared to the strongly calcium-sulfate signature of the Hickey Formation and alluvial/tailings wells (Figure 7-48). These data provide further support that the bedrock wells do not show an influence of the mine-impacted shallower groundwater.

7.6.2 Former Humboldt Smelter Property

Groundwater samples were collected at the former Humboldt Smelter property from wells located in the former Pyrometallurgical Operations area (MW-01S and GW-999948) and the Smelter Tailings Swale (MW-02S and MW-02D). Groundwater conditions in the Tailings Floodplain area are discussed separately (Section 7.6.3). Arsenic, nitrate, sulfate, and TDS exceed screening levels at the Humboldt Smelter site. The maximum concentrations detected include:

- Dissolved arsenic up to 0.362 mg/L (GW-999948)
- Dissolved lead up to 0.0044 mg/L (MW-02D)
- Nitrate + nitrite (as N) up to 530 mg/L (MW-01S)
- Sulfate up to 380 mg/L (MW-01S)
- TDS up to 18,000 mg/L (MW-01S)

The high TDS detected in MW-01S is associated with very high chloride concentrations (up to 5,400 mg/L) and elevated nitrate-nitrite and sulfate concentrations as noted above (MCL is 10 mg/L for nitrate). The water chemistry of this well, strongly sodium-chloride with very high TDS (Figure 7-48), is unique to the Site. MW-01S is located within the footprint of the dross area. The elevated TDS, nitrate, and chloride detected in MW-01S may be associated with releases of wastewater related to dross processing, leaching of exposed dross, or a combination of these processes. Elevated TDS concentrations have been detected in domestic wells located north of MW-01S: GW-999947, GW-999953, GW-999966 (Figure 7-55). The TDS concentrations in these wells range from 1,200 to 3,200 mg/L. The chloride and sulfate concentrations in these wells are also elevated (300 to 1,000 mg/L) relative to regional values, which are generally less than 75 mg/L (refer to Table 7-22 and Figure 7-54). Nitrate concentrations also exceed the MCL in GW-999947 and GW-999953 (Figure 7-53). Although these wells do not appear to be located directly downgradient of MW-01S groundwater, the groundwater flow direction is poorly constrained in this area. The TDS, chloride, sulfate, and nitrate impacts associated with the former Humboldt Smelter property may extend to these domestic wells. Additional investigation would be required to delineate the extent of Humboldt Smelter site impacts. There are other potential sources of these constituents (septic discharge, for example) that may be contributing to groundwater in this off-property area.

Reported selenium concentrations in well MW-01S have ranged from 0.118 to 0.306 mg/L (Table 7-19), consistently exceeding the MCL of 0.05 mg/L. The exceedances are localized to this well, and the source of the selenium is not clear. Selenium was not detected in leachate for most of the dross samples that were analyzed for metals leachability (refer to Section 8). Of the two samples where it was detected, the selenium concentration in the leachate was either below the MCL (0.018 J) or only slightly exceeded the MCL (0.062 mg/L). Leaching of selenium from dross does not appear to be the source of selenium impacts observed at these locations.

The elevated arsenic concentrations in GW-999948 appear to be localized to the immediate vicinity of this well (Figures 7-49 and 7-50). The construction details for this well are not known, but the general water chemistry characteristics (sodium-dominance, low chloride and sulfate, elevated arsenic) are most similar to the bedrock wells. This well also has a different chemistry from groundwater wells immediately to the north, described above, in that it does not reflect the high nitrate/chloride/TDS of these wells and MW-01S, further suggesting this well is screened in a different interval. The arsenic exceedances in MW-2D, which is completed in bedrock, appear to be associated with ambient water quality conditions, as described in Section 7.6.1. The concentrations reported in this well are similar to those for other EPA bedrock monitoring wells. Lead concentrations do not exceed the MCL.

7.6.3 Tailings Floodplain

Groundwater samples were collected in the Tailings Floodplain from four wells (CHF-MW-01 through CHF-MW-03, and STS-MW-04I) screened in alluvium, and tailings that have accumulated behind the Chaparral Gulch Dam. Arsenic, sulfate, and TDS exceeded screening levels. Dissolved lead was not detected in these wells. The maximum concentrations detected include:

- Dissolved arsenic up to 0.275 mg/L (CHF-MW-01)
- Nitrate + nitrite (as N) up to 5 mg/L (STS-MW-04I and CHF-MW-03)
- Sulfate up to 1,400 mg/L (CHF-MW-02)
- TDS up to 2,500 mg/L (STS-MW-04I)

The elevated arsenic, sulfate, and TDS detected in these wells are consistent with ARD mechanisms described in Section 7.6.1 for the Iron King Mine source areas. The high arsenic concentration in CHF-MW-01 appears to reflect the fact that the well is completed in saturated tailings.

Groundwater in the saturated tailings upstream of the dam seeps beneath or around the abutments of the dam. The sulfate and TDS in groundwater from the wells behind the dam are comparable to surface water samples collected immediately downstream. The dissolved arsenic concentrations in surface water downstream of the dam, however, are approximately an order of magnitude less than the arsenic concentrations in groundwater.

7.6.4 Off-Property Locations

Sulfate concentrations in the majority of off-property wells to the north and east of the former Iron King Mine and Humboldt Smelter properties are below 100 mg/L, and more commonly below 75 mg/L (Table 7-22). As discussed in Section 7.6.1, groundwater in the area between the properties displays impacts from the former Iron King Mine, most consistently reflected by sulfate concentrations as displayed on Figure 7-54. Wells GW-999903, GW-999945, GW-999958, and SW-08 have sulfate concentrations that range between 220 and 1,300 mg/L. The only other off-property area that displays mildly elevated sulfate is immediately north of the Humboldt Smelter property, represented by wells GW-999947, GW-999953, and GW-999966, with sulfate concentrations between 150 and 190 mg/L. As discussed in Section 7.6.2, these wells also display elevated TDS, chloride, and nitrate that may indicate an association with the very high TDS area around well MW-01S.

Sulfate is a more consistent indicator of Iron King Mine or Humboldt Smelter impacts to groundwater than arsenic in this area. Arsenic is common in natural rocks and soils of the area, outside of the mineralized zone of Iron King Mine and the waste materials of the former Humboldt Smelter property. Exceedance of the arsenic screening level is common in non-EPA wells of the area, including many that are clearly outside the pathway of groundwater flow from either property. An examination of the total and dissolved arsenic concentrations in Figures 7-50 and 7-51 show that the majority of private and public supply wells in Humboldt Proper near the Site have arsenic concentrations below the MCL, and where exceedances do occur, the concentrations are less than 0.03 mg/L. In contrast, almost all of the private supply wells northeast of the Site (to the east side of the Agua Fria River) and the two wells sampled to the south of the former smelter property (GW-567387 and GW-900344) have concentrations exceeding MCLs for arsenic, and in some cases, concentrations exceeding 0.1 mg/L. As discussed in Section 7.3, these are areas where naturally elevated concentrations of arsenic and other metals have been detected in soil and rock outcrops. These areas would not be subject to groundwater transport of site-related contamination. The groundwater flow direction in all hydrogeologic units (see Section 5.5.3 and Figure 5-11) is to the east (not south) of the Site, and groundwater discharges to the Agua Fria River as baseflow. Although there are no monitoring wells east of the Agua Fria River, groundwater flow also likely mirrors topography in this area and flows westward toward the Agua Fria River.

Humboldt Water Company has constructed an arsenic and reverse osmosis treatment system to improve the quality of water served (ADEQ, 2015b; Arizona Corporation Commission Utilities Division, 2015; Southwestern Utility Management, Inc., 2016). EPA, ATSDR, ADEQ, Arizona Department of Health Services, and other state and local health agencies are encouraging residents to test private well water for arsenic and lead, and if concentrations are above drinking water standards, to install a water treatment system (Arizona Department of Health Services, 2016).

Arsenic was found above screening levels in two wells located between the two properties (GW-999901 and GW-999908, Figures 7-49 and 7-50) that were not analyzed for sulfate to confirm impacts from the mine site. The concentrations in these wells (0.0146 and 0.017 mg/L) were within the range of off-property wells located further away and cross-gradient of the Site. In addition, other wells between the properties that did show elevated sulfate were consistently below arsenic screening levels. Elevated arsenic concentrations found in wells within the Town of Dewey-Humboldt and the surrounding area are naturally occurring. Groundwater in the area east of the Agua Fria River is more consistently elevated in arsenic, most likely due to the presence of arsenic-rich volcanic rocks in the hills to the east. The variability and magnitude of arsenic concentrations in the vicinity of the former Iron King Mine are consistent to these regional trends.

Although some samples exceeded screening levels for total lead (Figure 7-51), no off-property wells exceeded screening levels for dissolved lead (Figure 7-52). This is consistent with the general insolubility and strong adsorbing properties of lead in the pH range observed in groundwater at the Site.

Although elevated TDS is generally found where sulfate is elevated, there are other sources of TDS that are not associated with site activity, such as septic system infiltration. TDS exceeds screening levels in areas both near and far from the properties, indicating multiple sources.

Nitrate concentrations locally exceed the primary MCL in the Dewey-Humboldt area (Towne and Freark, 2000). The nitrate exceedances are suspected to be associated with older septic systems and past agricultural activities. Of the off-property samples analyzed for nitrate under EPA's RI (3 EPA well clusters and 11 other wells), six wells have shown exceedance of nitrate screening levels. Two of these wells (GW-999947 and GW-999953) were discussed above as possibly being influenced by Humboldt Smelter activity due to their proximity to very high nitrate in well MW-01S. The remaining wells likely have elevated nitrate from non-site-related sources.

7.7 Ambient Air

Ambient air samples were collected between August 2008 and September 2009 during the Initial RI (EA, 2010) to characterize the current sources and potential offsite migration of airborne COIs. Fine-grained materials (primarily tailings and dross) at the former Iron King Mine and Humboldt Smelter properties are potential sources for ambient air dispersion of dusts. Ambient air sampling data do not characterize historical aerial dispersion of contamination from Humboldt Smelter stack emissions or other mining and smelter activities.

Air samplers were placed at the former Iron King Mine property, former Humboldt Smelter property, Humboldt Proper, and locations thought to be indicative of background during the 2008 to 2009 Initial RI (EA, 2010) (see Figures 7-56 and 7-57). The sampling design was summarized in Section 4.2.6 and Table 4-1.

Samples were analyzed for TSP, PM_{10}, and inorganics. TSP data measure the total amount of matter in the air (such as all dust particles). PM_{10} data measure the concentration of particulates in the air that may enter the lungs. The particulate data were discussed in detail in the Initial RI (EA, 2010) and are summarized briefly in this section. The focus of this section is on the inorganic ambient air concentrations, as the inorganics have chemical-specific toxicity criteria and are used in the HHRA.

EA collected ambient air samples using two types of samplers:

- PQ100 samplers
- TEOM continuous particulate monitors (TEOM samples were collected when specified TSP thresholds were exceeded, and as a result, include episodic events that are not representative of the chronic conditions.)

Due to the different nature of sampling, inorganic data for the PQ100 samples and TEOM samples are shown separately on Figures 7-56 and 7-57. Inorganic data from PQ100 samplers are summarized in Table 7-23.

Residential RSLs (EPA, 2015a) were used as screening levels for ambient air concentrations, as presented in Section 6.3. Screening levels were used solely to provide a perspective for identifying the nature and extent of contamination, and are not intended to infer the existence of unacceptable risk. Rather, the risk assessment summarized in Section 9 provides site-specific estimates of risk. Screening levels and exceedances for the inorganics are presented in Table 6-6.

Aluminum, arsenic, beryllium, cadmium, lead, and nickel exceeded screening levels and are considered COIs. Of these constituents, although arsenic exceeds the screening level for more samples than the other COIs, the analyses presented in Sections 9.6.5 and 9.7.1 demonstrate that unacceptable residential health risks were not identified for any of the ambient air monitoring stations near current residential areas.

7.7.1 Wind Data

A meteorological station monitored wind speed and direction at the former Iron King Mine between August 2008 and August 2009 (EA, 2010), during the period of ambient air sampling. The meteorological station was located in the southeastern portion of the NAI Operations area, near sample location AIK-02 (see Figure 4-6). Wind data are discussed in Section 5.2, and windrose diagrams are presented on

Figure 5-4. Wind directions were variable at the Site, but for most of the year, the prevailing wind was from the south and southeast. During the months of November, December, and January, however, the prevailing wind direction was from the northwest. Average wind speeds commonly exceeded 5 mph. As discussed in Section 5.2, the location of this meteorological station was 100 to 150 feet lower in elevation than the upper portion of the MTP. Average wind speeds at higher elevations on the Site or during years with a greater frequency of storm events or higher intensity storm events could be greater than those measured.

7.7.2 Particulate Data

The Initial RI included a detailed analysis of the TSP and PM_{10} data (EA, 2010). It concluded that moderate to high wind events that occur throughout the year transport fine-grained materials and particulates (tailings, dross, impacted soil, or road dust) from the former Iron King Mine and Humboldt Smelter properties. Conclusions from the Initial RI are summarized below; figures and tables from the Initial RI (EA, 2010) showing air monitoring data are reproduced and presented in Appendix N.

The Initial RI concluded that the TEOM PM_{10} concentrations in ambient air exhibited great variability over short periods of time, especially in March and early April 2009; these were classified as peak events. These peak events tended to correlate with peak wind speeds. Although the PM_{10} concentrations were also elevated in May 2009, there were very few peak events. In June 2009, PM_{10} concentrations were lower on average. In July and August 2009, PM_{10} concentrations increased and peak events became more frequent; this is likely associated with monsoon season thunderstorms.

Very high TEOM PM_{10} concentrations (for example, 580 micrograms per cubic meter [$\mu g/m^3$] at the former Iron King Mine and 6,900 $\mu g/m^3$ at the former Humboldt Smelter) during peak events are indicators that migration of particulates is occurring. The magnitude of the peak PM_{10} concentrations was higher at the former Humboldt Smelter property than at the former Iron King Mine property or Humboldt Proper stations. Average PM_{10} concentrations were similar at all stations, suggesting a regional baseline of PM_{10} in ambient air.

There was also a seasonal component to TSP concentrations in that concentrations tend to be higher in May and August 2009. The PQ100 samplers did not capture the peak wind events in March and early April 2009 that were evident in the TEOM data; these occurred when the PQ100 samplers were not collecting samples.

TSP concentrations at the Humboldt Proper, former Humboldt Smelter, and former Iron King Mine sampling stations were similar on average. However, all three sampling stations had TSP concentrations higher than the background station, on average. This is likely due to a combination of anthropogenic activities (for example, driving on dirt roads) and the lack of vegetative cover near all three locations (dirt parking lot near the Humboldt Property location, the dross piles near the former Humboldt Smelter location, and the tailings near the former Iron King Mine locations).

7.7.3 Inorganic Data

The maximum detections of the primary COIs in air samples collected using PQ100 samplers are shown on Figure 7-56. The maximum detections in samples collected using TEOM samplers are shown on Figure 7-57. A comparison of the maximum detections with screening levels for the PQ100 and TEOM sample data is presented in Table 6-6, and a summary of the PQ100 sample data is presented in Table 7-23. Inorganic data are discussed by constituent below.

Inorganic ambient air data indicate the Iron King Mine source areas are acting as potential sources for arsenic migration during high wind events. Ambient air sampled at the former Iron King Mine property had higher concentrations of arsenic than other air sample locations. Concentrations of arsenic in Humboldt Proper and the former Pyrometallurgical Operations area were similar to background concentrations. Similarly, inorganic ambient air data indicate that Humboldt Smelter source areas could be a potential source of aluminum and lead migration via aerial dispersion. As presented in Sections 9.6.5 and 9.7.1, no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas.

7.7.3.1 Arsenic

Arsenic concentrations exceeded screening levels in a subset of samples collected from all four areas of the Site (former Iron King Mine, former Humboldt Smelter, Humboldt Proper, and background locations). Arsenic was detected near the Humboldt Elementary School (location AES-01) at concentrations of 0.00014 to 0.011 µg/m^3 using the PQ100 samplers, which was similar to the range of arsenic concentrations at the background location ABG-01 (maximum detection of 0.012 µg/m^3). As discussed for soil and sediment, arsenic is commonly found in the volcanic rocks of the region, and background concentrations of arsenic are elevated.

Arsenic exceeded its screening level more frequently compared with other COIs (arsenic exceeded the screening level in approximately 20 percent of the samples; other COIs exceeded the respective screening levels in 6 percent or less of the samples). As shown on Figures 7-56 and 7-57, ambient air in the vicinity of the Iron King Mine (locations AIK-1, AIK-01A, and AIK-02) had the highest detections of arsenic, with a maximum detection of up to 0.035 µg/m^3. These maximum arsenic concentrations detected at the former Iron King Mine property were approximately two to three times greater than the maximum arsenic detected at other locations onsite. Although ambient air arsenic concentrations were elevated immediately adjacent to the MTP, as discussed in Sections 9.6.5 and 9.7.1, no unacceptable residential health risks were identified near current residential areas.

7.7.3.2 Lead

Ambient air concentrations of lead only exceeded screening levels in one sample collected from the former Humboldt Smelter (location AHS-02A). This lead concentration of 0.18 µg/m^3, detected at AHS-02A in January 2009, only marginally exceeded the screening level of 0.15 µg/m^3, but was an order of magnitude greater than lead concentrations detected elsewhere onsite. No unacceptable residential health risks were identified at this location.

7.7.3.3 Aluminum

Aluminum concentrations exceeded screening levels in four samples collected by the PQ100 samplers and one TEOM sample. Samples with exceedances were collected at two locations:

- AHS-01: Classified as a background (upwind) monitoring station in the Initial RI (EA, 2010). Located south of the Humboldt Smelter property boundary; maximum detection of 64 µg/m^3 recorded in August 2008.
- AHS-02A: Located at the former Humboldt Smelter; maximum aluminum concentration of 20 µg/m^3 detected using the TEOM sampler.

The dross is expected to be a concentrated source of aluminum at the former Humboldt Smelter property. However, aluminum also occurs in enriched concentrations in volcanic rocks (especially rhyolite) encountered within the region (CH2M, 2015).

Aluminum was not detected, or was detected at concentrations below screening levels, at the other background sampling location (ABG-01), at all locations at the former Iron King Mine property, and in Humboldt Proper.

7.7.3.4 Beryllium

Beryllium exceeded screening levels in only three samples, as follows.

- AHS-02A: Located at the former Humboldt Smelter; maximum beryllium concentration of 0.016 µg/m^3 detected in January 2009.
- AHS-01: Classified as background in the Initial RI (EA, 2010), but located just south of the former Humboldt Smelter property boundary; maximum detection of 0.0018 µg/m^3 (August 2008) only marginally exceeds screening level of 0.0012 µg/m^3.
- AIK-03: Humboldt Proper sample location; maximum beryllium detection of 0.0014 µg/m^3 (August 2008) only marginally exceeds screening level of 0.0012 µg/m^3.

The beryllium concentrations at Humboldt Smelter (AHS-02A) were an order of magnitude higher than other detections onsite. However, as discussed in Section 9, no unacceptable residential health risks were identified at this location or near current residential areas.

7.7.3.5 Cadmium

Cadmium concentrations exceeded screening levels in eight samples collected by the PQ100 samplers and two TEOM samples. The maximum cadmium concentrations (0.0036 µg/m^3 for the PQ100 samples and 0.0055 µg/m^3 for the TEOM samples) only marginally exceeded the screening level of 0.0016 µg/m^3. All exceedances were J-flagged, indicating the concentrations were approximate.

There was not a clear pattern of cadmium concentrations with distance from the mine source areas. The maximum cadmium concentration of 0.0055 µg/m^3 was detected in a TEOM sample collected near the Humboldt Elementary School (AES-01). Cadmium was nondetect or below screening levels in the remaining 27 TEOM samples and all 36 PQ100 samples at this location. However, as discussed in Section 9, no unacceptable residential health risks were identified at the Humboldt Elementary School or near other current residential areas.

7.7.3.6 Nickel

Nickel concentrations were below the screening level in samples collected near the Humboldt Elementary School (AES-01) and the background location (ABG-01). Nickel concentrations exceeded the screening level at the majority of the other locations, including background (upwind) location AHS-01. The maximum nickel concentrations were detected on the former Iron King Mine and Humboldt Smelter properties at the following locations:

- AIK-02: Located at the former Iron King Mine; maximum detection of 0.14 µg/m^3 recorded in April 2009.
- AHS-02A: Located at the former Humboldt Smelter; maximum nickel detection of 0.099 µg/m^3 was detected using the TEOM sampler.

Table 7-1 provides a summary of the nature and extent evaluation presented in this section. Information and analyses presented in the nature and extent evaluation are used to describe the fate, transport, and potential migration pathways of contaminants in Section 8.

SECTION 8

Contaminant Fate and Transport

Section 7 described the contamination found in soils, sediments, surface water, groundwater, and ambient air resulting from underground mining and production of ore, waste rock, and waste at the Iron King Mine; ore processing and smelting at the Humboldt Smelter; and the release of tailings and other waste materials to the environment at both sites. Contaminant transport mechanisms common to mines, smelters, and ore processing facilities include:

- Operational releases
- ARD discharges to groundwater or surface water
- Metal leaching of soils, tailings, or sediments
- Surface water transport of contaminated soils
- Aerial dispersion (from historical stack emissions and ongoing transport of windblown particulates)
- Groundwater transport
- Other anthropogenic transport mechanisms

This section evaluates the contaminant transport mechanisms associated with the former Iron King Mine and former Humboldt Smelter properties. It provides a description of how contaminated materials were placed into the environment at each of these properties and potential mechanisms for how these contaminants may continue to move in the environment. The risks to human health and the environment from the contaminants are described in Sections 9 and Section 10, respectively.

Section 8 is organized into the following subsections:

- Section 8.1 – describes chemical mechanisms for production of ARD and evaluates of the potential for ARD production through measuring ABA parameters.

- Section 8.2 – describes contaminant release and transport mechanisms (operations, ARD, metals leaching, and surface water) at the former Iron King Mine property.

- Section 8.3 – describes contaminant release and transport mechanisms (operations, ARD, metals leaching, and surface water) at the former Humboldt Smelter property.

- Section 8.4 – describes formation, contaminant release, and transport mechanisms (operations, ARD, metals leaching, and surface water) at the Tailings Floodplain.

- Section 8.5 – describes transport mechanisms on a sitewide basis, including aerial dispersion, groundwater transport, and anthropogenic factors.

- Section 8.6 – presents a CSM (conceptual site model), summarizing significant features, physical characteristics, source areas and releases, and the fate and transport of contamination.

Mining and smelting activities resulted in formation of numerous waste piles (tailings, waste rock, and ore materials) at both the former Iron King Mine and Humboldt Smelter properties, and adjacent areas. Understanding contaminant fate and transport mechanisms requires an understanding of (1) how the contaminated materials were first placed, (2) the physical site features, and (3) the nature and extent of the contamination. Sections 2, 5, and 7 detail the current understanding related to each of these subject areas for the former Iron King Mine and Humboldt Smelter properties. To the extent required to support the description of the fate and transport mechanisms, pertinent data and information from these sections is included in Section 8.

8.1 Acid Rock Drainage Production

8.1.1 Chemical Reactions

Under the right physical and chemical conditions, mining of ores containing iron sulfide (pyrite) can result in the formation of acid rock drainage (ARD). ARD is formed by the oxidation of sulfide minerals when they are exposed to water and air, causing partial dissolution. Sulfuric acid, heat, and ferric iron are formed during ARD production. Trace metals that are present in the sulfides, such as copper, cadmium, zinc, and lead, may also be released in the dissolution process and remain stable in water under the low pH conditions created by the ARD. ARD can occur in dewatered mine workings, waste rock, and tailings.

Simultaneous with the iron oxidation, arsenic can also be mobilized and be released during ARD generation. Microscopic bacteria, typically present in all environments, oxidize the sulfide minerals as a source of energy and accelerate the reactions forming ARD.

The dissolved metals will remain mobile until changed conditions (such as higher pH) cause the metals to re-precipitate and drop out of solution and/or re-sorb to soils, sediment, or rock. In some cases, the acid generated by ARD reactions is neutralized by sources of buffering capacity or alkalinity in the waste material or in the surrounding environment. When this happens, the metals released by the reaction may be precipitated and sulfate is the primary ARD reaction product to remain mobilized in groundwater or surface water.

Mine tailings, in particular, can accentuate ARD production because they are the waste product from processing the ore after it has been crushed and ground to a fine particle size (generally sand and silt sized). The fine particle size facilitates the infiltration of water and air (as compared, for example, to solid rock) and provides a greater contact surface area for the reaction to occur. ARD production at any given location is dependent on many factors, including the particular chemical composition and ore mineralogy, the physical properties of the ore-based waste (such as particle size), the chemical characteristics of the groundwater, surface water, or surrounding soils, pH, and available buffering capacity or neutralizing potential. Therefore, not all mines, ores or tailings will produce ARD nor will the same chemicals be mobilized if ARD is produced.

Both the potential for, and the actual generation of, ARD must be evaluated in a remedial investigation at mining sites because ARD can greatly facilitate the migration of metals from mines and mine waste to environmental media such as sediments, water bodies, groundwater, soils, or air (such as sediment dust after drying). The metals can be transported to locations distant from the original mine sources, causing toxicity to organisms at those locations.

Mining and smelting activities have fundamentally altered the geochemical and hydrologic conditions at the former Iron King Mine and Humboldt Smelter properties. In an undisturbed condition, the sulfide minerals and ore bodies would remain in place in solid rock and below the water table, and would not be exposed to oxygen that would trigger ARD. Mine wastes, such as waste rock and tailings, contain environmentally significant concentrations of trace metals within reactive sulfide minerals. Deposition of these mine wastes at the surface and subsequent oxidation of the sulfide minerals result in the generation of heat, dissolved metals, sulfate, and ARD.

As discussed in Section 5, metals such as iron, zinc, and lead are present in the sulfide mineral deposit at the former Iron King Mine property, as well arsenic, cadmium, copper, and gold. When iron sulfide (pyrite), by far the most common sulfide, is exposed to moisture and an oxidant (such as free oxygen or aqueous ferric iron), the pyrite oxidizes and releases hydrogen ions that acidify the water contacting the mineral. Arsenic is a common impurity in pyrite and other sulfides, and is also released in this partial dissolution reaction. In parallel chemical reactions, heavy metals dissolve into the acidic water generated by the pyrite oxidation reaction. Equation 1 shows the oxidation reaction of pyrite (FeS_2)

with free oxygen as the oxidant. Equation 2 below shows the reaction with aqueous ferric iron (Fe^{3+}) as the oxidant.

$$FeS_2 + \tfrac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \tag{1}$$

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \tag{2}$$

Both of these oxidation reactions occur in the waste rock and tailings materials at the former Iron King Mine property. Ferric iron, as the oxidant in Equation 2, is made available at pH values less than 3.5 by the reaction shown in Equation 3. Typically, at a pH of less than 3.5, the rate of reaction for Equation 3 would be extremely slow, but at mining sites such as the former Iron King Mine property, a biological catalyst can accelerate this oxidation reaction.

$$Fe^{2+} + \tfrac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2}H_2O \tag{3}$$

The presence of Fe^{3+} also perpetuates the dissolution of other metal sulfides, as shown in Equations 4a and 4b. "M" represents transition metals such as cadmium, copper, lead, zinc, and combinations of these metals. Some examples of metal sulfides besides pyrite are sphalerite (zinc sulfide) and galena (lead sulfide), which could participate as reactants in Equation 4a. Equations 4a and 4b are analogous to Equation 2, but are generalized for metal sulfides. Ferric iron again acts as the oxidant (in place of oxidation by free oxygen, as represented by Equation 1) and additional hydrogen ions are released.

$$MS + 8Fe^{3+} + 4H_2O \rightarrow M^{2+} + 8Fe^{2+} + SO_4^{2-} + 8H^+ \tag{4a}$$

$$MS_2 + 14Fe^{3+} + 8H_2O \rightarrow M^{2+} + 14Fe^{2+} + 2SO_4^{2-} + 16H^+ \tag{4b}$$

These ferric iron-oxidized reactions occur only at low pH; the metal sulfide mineral can dissolve via oxidation due to reaction with oxygen (Equation 1) at higher pH. Trace metals are also commonly present in pyrite in trace amounts, and therefore may also be released directly during pyrite oxidation by oxygen, shown in Equation 1.

Ferric iron will also act to generate acid when the pH rises above 3.5 by precipitating as a hydroxide mineral:

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3(s) + 3H^+ \tag{5}$$

The former Iron King Mine property provides the largest base metal massive sulfide deposit in the region, and consequently is expected to be a primary source of base metals such as zinc and cadmium in comparison to the rest of the region. Arsenic is associated with the mineralization at the former Iron King Mine property due to the presence of arsenic-bearing sulfide minerals. However, the Iron King Mine deposit is not the only mineral deposit in the region with arsenic-bearing minerals. Arsenic is also associated with silicic volcanic materials such as rhyolite and mineralized veins, which are widely present throughout the region.

The ARD generated by the waste materials, barring no subsequent reactions, can discharge from the leached materials, resulting in local impacts to groundwater and surface water. However, the local solids may contain other materials that can act to adjust the pH upward, and in some cases attenuate the metals released by these reactions. This is discussed in Section 8.1.2

8.1.2 Acid-Base Accounting

The potential to generate ARD is evaluated through testing to provide data pertaining to *"acid-base accounting"* or "ABA." ABA parameters include acid-generating potential (AP), neutralizing potential (NP), and net neutralization potential (NNP), which equals the difference between NP and AP.

The ABA parameters provide a measure of whether a sample is capable of producing acid, through the oxidation of sulfide minerals, and/or neutralizing acid with carbonate minerals (and to a lesser extent with silicate minerals). Total sulfur analysis is conducted along with sulfate and organo-sulfur analyses. The difference between total sulfur and sulfate plus organo-sulfur provides an estimate of sulfide content. The vast majority of sulfide in samples from the Site is assumed to be pyrite (iron sulfide), which is by far the most common sulfide mineral. Oxidation of pyrite produces acid through a series of reactions described in Section 8.1.1. This acid may be neutralized by reaction with carbonate minerals, the most common being calcium carbonate (calcite, also referred to as $CaCO_3$):

$$CaCO_3(s) + H^+ \rightarrow HCO_3^- + Ca^{2+}$$

The three parameters AP, NP, and NNP are reported in units of kilograms of calcium carbonate per metric ton (kg $CaCO_3$/tn) by convention. Similarly, the ratio of NP to AP may be reported as the neutralization potential ratio (NPR). These parameters are used as follows to evaluate the potential for producing ARD:

- If a sample has measurable NP, it may presently appear neutral and not acid-generating, but if its AP is greater than its NP, then the NP will eventually be consumed, with the excess acid producing acidic leachate.
- NNP provides an estimate of whether the sample will either presently or eventually produce acid. A negative value of NNP indicates acid will be generated, while a positive value indicates that there is excess NP that will continue to neutralize the AP until the AP is used up. In practice, values of NNP between -20 and 20 kg $CaCO_3$/tn indicate an uncertain outcome over time, and for these samples kinetic testing has been recommended (EPA, 1994). However, for conditions where both the AP and NP are very low, NNP results in this range indicate that although the outcome is uncertain, the material would be, at most, a potential weak acid generator.
- For NPR, a ratio less than 1 generally indicates the sample is acid-generating, while a ratio greater than 3 indicates the sample will not generate acid, with ratios in between these values considered uncertain (EPA, 1994).

8.2 Former Iron King Mine Property Contaminant Release and Transport Mechanisms

This section summarizes the contaminant release and transport mechanisms specific to the former Iron King Mine property, including the mechanisms of release from sources areas such as the MTP, the former Small Tailings Pile, and waste rock piles found in the former Mineworks area/former Fertilizer Plant area. Release mechanisms specific to the former Humboldt Smelter property are discussed in Section 8.3.

8.2.1 Contaminant Release during Historical Operations

Mechanisms that may have caused a direct release of contaminants into the environment during the historical operations at the former Iron King Mine property can be grouped into three categories:

1. Discharge of contaminated wastes, including mine process water discharge and stormwater discharge through drainage tributaries
2. Impoundment failures and erosion of wastes, including tailings released from the MTP prior to, during, and following the MTP 1964 Blow Out event
3. Placement or dumping of mine wastes, including spillage of waste during milling and ore transportation, and direct soil contamination and erosion of waste from the former Small Tailings Pile

Contaminants released through direct discharge may be subsequently transported by surface water, groundwater, or aerial transport mechanisms. Transport of contaminants via surface water from the former Iron King Mine Property is discussed in Section 8.2.4. Aerial transport of dust from waste accumulations from the former Iron King Mine property, and by dust and smelter stack emissions from the former Humboldt Smelter property, is discussed in Section 8.5.1. Transport of contaminants in groundwater is discussed in Section 8.5.2.

General Nature of Mine Tailings

As discussed in Section 2.1.2, the most prominent feature at the former Iron King Mine is a mine tailings pile (known as the Main Tailings Pile or MTP) with a volume of between 3 and 4 million yd^3. The Iron King Mine facility not only mined ores from the ground but also milled (ground) the ores and treated them in a process known as *concentration*. In concentration, milled ore is placed into floatation cells called concentrators and mixed with additives to encourage the mineral particles with the saleable metal of interest to either float or sink (that is, *to separate*) from the other earthen particles. The fraction with the metal of interest is then called *concentrate*; while the remaining fraction is called *tailings*. When wet, tailings take the form of a sludge; when dry, tailings are generally fine-grained and sand- or even powder-like material. In the mining and smelting industries, tailings are often treated as waste, though they sometimes can be reprocessed to enable the recovery of metals other than those concentrated in the original process. At mining or smelting facilities, tailings sludges are often sluiced or tremmied into ponds for storage or disposal. Such ponds were often built into bowl-shaped depressions in slopes, or against a slope with berms and buttresses that are raised as the amount of waste increases. After operations cease, such ponds can gradually desiccate, leaving a dry pile, potentially with more saturated material in the center.

As is shown in the 1940 photograph (Figure 3 in Appendix C) and the 1955 photograph (Figure 11 in Appendix B), the Iron King Mine Tailings Pile was originally two small tailings ponds that expanded tremendously in the 15 years between 1935 and 1955.

8.2.1.1 Process Water and Stormwater Discharge

During operations at the former Iron King Mine property, direct discharge of process water into surrounding drainages likely occurred. Water for milling operations was pumped from the bottom of Shaft 6 and from company-owned wells on the Agua Fria River, as discussed in Section 2.3.2.4 (USDI Bureau of Mines, 1950). Water would have been added to the crusher discharge to produce a slurry for subsequent milling processes (grinding, flotation, and gravity separation). Because pumping of the mine workings was not able to supply all of the mine and mill requirements, and additional supply from wells was required, there would have been a cost to provide water and water would likely have been recycled when possible to minimize pumping costs. However, it is also likely that operational water discharges would have taken place from the mill and tailings ponds.

Outfalls were observed in 1940 and 1953 aerial photographs associated with the tailings ponds, and may have been used to discharge operational water as described in Appendix C (EPA, 2008d). Overflow from the tailings ponds would have occurred during periodic large storm events that exceeded the water retention capacity even if breaches of the tailings ponds had not occurred. As shown in the aerial photograph, overflow would have carried fine tailings particles downstream to Chaparral Gulch via either tributary drainages north of the Iron King Mine, or the drainage along what is now Third Street. Also, when water quality deteriorated during processing (for example, from buildup of fine particles that settle very slowly, or dissolved constituents that interfered with process chemistry), process water may have been discharged rather than recycled.

It is unknown how tailings were managed during very early mining operations. Tailings may have been contained in smaller precursor tailings ponds, or potentially discharged directly to the intermittent drainages. The aerial photographs (Appendix C) show that discharges occurred from areas that mine shafts were located to both Chaparral Gulch and Galena Gulch.

Stormwater releases occurred during fertilizer operations at the NAI Operations area (described in Section 3). Stormwater retention ponds at NAI were observed to collect runoff from the north side of the MTP and from the MTP, and overflow to a drainage channel that enters Chaparral Gulch (EA, 2010). Both ponds contained tailings.

8.2.1.2 Impoundment Failures and Erosion of Wastes

Tailings pond failures occurred a number of times over the history of operations at the former Iron King Mine property. The aerial photographs (Appendix C) identify berm breeches in smaller tailings ponds in the Chaparral Gulch tributaries prior to the MTP 1964 Blow Out, although the 1964 event was the largest single event. During the MTP Blow Out, a significant portion of the MTP tailings slumped and accumulated behind a berm formed by the historic rail bed west of State Highway 69. Some of the released tailings (likely finer-grain size) were transported east of State Highway 69, parallel to the current location of Third Street, and into Chaparral Gulch, which feeds the Agua Fria River to the east. Tailings in the MTP are generally composed of silt, silty sand, or sandy silt (Table 7-3).

Material in this size range can be eroded and transported by moderate water velocities. The mine manager estimated that 5,000 tons of the tailings were transported to the Agua Fria River (Kentro, 1964). The historical aerial photographs (Appendix C) show that waste rock and tailings materials were placed in drainages that discharged to both Galena and Chaparral Gulches. These materials were erodible during large storm events. These release and transport mechanisms are still occurring and are discussed in detail in Section 8.2.4 (Surface Water Transport).

8.2.1.3 Placement or Dumping of Waste

An additional source of contaminant releases may have originated from the processing and transportation of material around, or from, the Site, which may have caused ore or wastes to be dumped on the ground. When the former Mineworks area was in operation, for example, ore was hoisted from the mineshafts and transported to the former Mineworks area mill for processing. Ore was transferred from the mineshaft to the mill by a 24-inch conveyor belt. A detailed discussion of the ore milling process is presented in Section 2.1.2.1. Concentrates from the ore processing were hauled by truck about ½ mile to a railroad siding where the material was loaded onto railcar bins for transport to various smelters for processing (EPA, 2009c). Spillage during the material transport process likely resulted in contaminant release.

The former Small Tailings Pile was also used for placement of waste. This pile was located north of the MTP outside the former Iron King Mine property boundary (Figure 2-1) on a 40-acre residential parcel, along a drainage tributary to Chaparral Gulch, which borders the pile to the north and east. In addition to direct soil contamination resulting from placement of this pile, erosion of these tailings likely occurred prior to its removal in 2011.

8.2.2 Acid Rock Drainage at former Iron King Property

The leaching of acidic products from surface and near-surface mine waste sources, primarily tailings, is of primary concern at the former Iron King Mine property, compared to the deeper saturated materials. While the mine water sampled from the flooded mine workings contains elevated concentrations of trace metals and sulfate (Section 7.6.1), this contamination likely occurred as a result of dissolution of mineral salts produced while the mine was dewatered. However, because the mine workings are located far below the water table and no longer exposed to oxygen due to flooding of the mine, production of these salts has been shut down. The mine workings are not expected to play a role in groundwater contamination in the shallower zones, where human and ecological exposure is possible.

Groundwater samples from the upper zones of the bedrock across the Site support this conclusion, with little or no evidence of these sulfide oxidation products.

8.2.2.1 Acid-Base Accounting

A total of 24 samples from the former Iron King Mine property and the adjacent area were analyzed for ABA parameters. Figure 8-1 shows the locations of these samples.

The samples represented a range of materials, including tailings, waste rock, and natural rock and soil. ABA data are provided in Table 8-1, grouped by exposure area. Relevant findings pertaining to the former Iron King Mine area are summarized below:

- **Former Iron King Mine Property Tailings.** All 15 tailings samples from the MTP have negative NNP values that range between -47 and -417 kg $CaCO_3$/tn, with an average of -221 kg $CaCO_3$/tn, indicating that Iron King Mine tailings are acid generating. Paste pH values range from 2.2 to 7.5. Paste pH is a measurement of the pH of a mixture of soil and distilled water in a ratio of 1:1 by weight.
- **Former Iron King Mine Property Waste Rock.** The three waste rock samples have NNP values that vary over a wide range (-119 to 130 kg $CaCO_3$/tn). This variability may be due to the heterogeneous nature of the waste rock, which can contain both barren and mineralized (sulfide-bearing) rock. These results suggest that where it is mineralized, the waste rock is acid generating. Paste pH values range from 6.3 to 7.8.
- **Natural Rock and Soil.** The two samples from the Hickey Formation were collected at the bottom of borings drilled through the MTP. In contrast to the strongly negative NNP of the tailings, the Hickey samples were 1 and 10 kg $CaCO_3$/tn, indicating uncertain but potentially weak acid-generating characteristics. These values suggest a slight influence of the overlying tailings in the sample material. The four soil samples collected around the periphery of the Iron King Mine area (two in the Auto Yard and two east of the mine property) range in NNP from 14 to 148 kg $CaCO_3$/tn, reflecting uncertain but potentially weak acid-generating to neutralizing characteristics.

Figure 8-2 is a plot of NNP versus paste pH for all samples. Samples with paste pH below 5.0 not only have negative NNP, but their measured NP values were all below the detection limit, indicating that NP for these samples has been consumed, and they are no longer buffered. This group includes surficial tailings samples from the MTP and Chaparral Gulch. Conversely, samples with pH above 7.5 are either neutral (equal AP and NP) or have little AP remaining (buffered). The remaining samples between 5.0 and 7.5 indicate that both acid production and neutralization capacity remain; samples with low NNP values (less than -20 kg $CaCO_3$/tn) will likely eventually become acidic.

Based on the ABA results, tailings from the MTP are acid-generating materials. Waste rock indicates similar results in samples that contain sulfide minerals, while other samples represent background (unmineralized) rock material. Other factors including moisture content, redox conditions, and transport processes can influence the generation of acidic conditions in these materials. For example, the tailings samples from the Iron King Mine with the lowest paste pH values were collected from surface exposures of the MTP, where conditions are expected to be aerobic. Deeper samples generally have higher paste pH values (buffering capacity remains), possibly because the available oxygen was consumed through ARD reactions in the upper MTP, and relatively little oxygenated water reaches the lower portion of the tailings.

The MTP contains an estimated 3.5 million yd^3 of tailings, compared to the combined volume of tailings in the Chaparral Gulch floodplain and the Smelter Swale of approximately 187,000 yd^3 (see Section 7.2.5). Tailings at the former Iron King Mine property therefore constitute a large, long-term source of ARD. The timing and degree to which this ARD impacts surface water and groundwater is dependent upon a number of factors, which are discussed in the following section.

8.2.2.2 Fate and Transport of Acid Rock Drainage

The MTP is the largest potential ARD source at the former Iron King Mine property. The generation and transport of ARD from the MTP is influenced by several physical properties of the tailings in addition to the chemical properties (AP, NP, and NNP) discussed in Section 8.1.2. The moisture content, particle size distribution, hydraulic conductivity of the tailings, and water infiltration rate all affect the rate and extent of ARD generation and subsequent transport of ARD products. The tailings in the MTP are oxidized near the surface (less than 2 feet deep in the borings advanced by SERAS in 2014) and appear reduced at deeper depths.

Moisture content influences oxygen transport into the tailings with generally lower oxygen transport at higher moisture content. Lower oxygen transport results in decreased oxidation of the tailings. The particle size distribution influences the rate of chemical reaction with smaller particles having higher surface area available for reaction, but finer particle sizes also result in lower hydraulic conductivity, and, hence, lower rates of vertical water transport downward through the tailings. The transport of ARD reaction products from tailings is influenced by the hydraulic conductivity and water infiltration rate of the tailings, with less water (and hence less ARD) transported through the tailings at lower hydraulic conductivities.

Moisture content in MTP tailings is variable among the samples collected (ranges from 12 to 98 percent calculated saturation), with no consistent trend with depth (see Section 7.2.1). Groundwater levels in monitoring wells screened within the tailings have generally shown that the groundwater level is below the base of the tailings; however, two wells (MW-8S and MW-9S) had groundwater levels slightly above the base of the tailings in October 2012 and June/July 2014, but were dry in October 2014 (Table 5-5).

The conceptual model of water infiltration through the tailings is that this occurs episodically, triggered by significant rain events. When a storm event occurs, rainwater accumulates at the top of the piles and slowly begins to infiltrate. This process continues following the rain event, as ponded water has been observed on the piles during site visits. The surface of the MTP is crusted and somewhat cemented, which may reduce, but does not eliminate, infiltration. Wetting and drying cycles on the surface of the MTP result in the formation of efflorescent salts. Formation of these salts is discussed in more detail in Section 8.3.4.4.

A portion of the precipitation that falls on the MTP evaporates, and the remainder infiltrates, effectively pushing entrained water vertically downward through the unsaturated tailings. The degree of saturation of the tailings is likely variable over time, based on the precipitation pattern. Dissolved salts that have accumulated in the entrained water, along with freshly leached salts in the infiltrating water, are transported downward through the pile and eventually through the native soil to the water table. This is likely a slow transport process given the limited rainfall (average annual precipitation of 13 inches) and episodic nature of significant rainfall events, along with the low permeability of the tailings as documented in Table 7-3.

The composition of leachate from waste materials found at the former Iron King Mine property depends on the ABA properties of the solids themselves. While the tailings ABA data show consistently net acid-generating qualities, there is still measurable NP in most of these samples, meaning that leachate pH will tend to remain neutral or near-neutral until this NP is completely used up.

The timing of the transition between neutral and acidic conditions is difficult to predict, with the main factors being the average water infiltration and oxygen transport rates through the material and changing flow paths of infiltration over time. Infiltration rates are influenced by material grain size and hydraulic conductivity. Tailings samples from the MTP have a median vertical hydraulic conductivity of 1.4×10^{-5} cm/sec (Table 7-3), a typical value corresponding to silt. This correlates well with the median percentage of fines (silt-clay-sized particles) of 72 percent. Although the data in Table 7-3 show a wide variation, the infiltration rate through the tailings would be expected to be slow relative to the comparatively more sandy material that makes up the natural soils of the area. Infiltration flow paths can shift due to preferred pathways being blocked by settling or precipitation reactions. This can result in an acidic leachate flowing into previously unexposed NP, returning the pH to more neutral levels.

Oxygen transport is influenced by both air and water flow through the tailings pile with moisture content and degree of saturation influencing the oxygen transport rate. The limited oxidation of the tailings with depth in the MTP indicates that the rate of oxygen transport into the pile is low compared to the oxygen demand required to oxidize the sulfides in the tailings. This indicates that oxidation of the tailings and generation of ARD is proceeding, but the oxidation front is moving slowly through the tailings, with it migrating only several feet over the last 45 years since the Iron King Mine ceased operation.

In tailings and waste rock in which NP remains active, the pH may be maintained at a circum-neutral level, but sulfate and trace metals released by the oxidation of sulfide minerals may still be mobile or partially mobile under these conditions. The groundwater monitoring well data reflect these effects, with several examples of elevated sulfate and arsenic, while pH remains in the 6 to 7 range (discussed in Section 8.5.2).

ARD generated in tailings from operations at the former Iron King Mine property, either in the MTP or tailings transported into downstream drainages, will flow along the surface and/or through the vadose zone, interacting with surrounding soil minerals. Surface flow has occurred historically through tributaries of Chaparral Gulch, likely a mixture of mostly surface runoff combined with some tailings seepage. This water would be expected to partially or fully infiltrate to groundwater along the downstream direction. Direct infiltration to groundwater from the tailings pile follows site groundwater gradients in the general direction of Chaparral Gulch and the Agua Fria River. The natural materials in the surface channels and vadose zone may also have quantities of NP that are sufficient to buffer the pH during recharge toward the groundwater table, even if the emerging leachate from the waste materials is acidic. In addition, minerals within the aquifer matrix can provide surface area for adsorption of trace elements such as arsenic, lead, and zinc, acting to attenuate their transport into and through groundwater. These adsorbent minerals include additional precipitates of iron hydroxide.

The degree to which ARD qualities emerge in groundwater, along with the timing of this emergence, depends on factors such as infiltration rates through waste materials, recharge rate to groundwater, and geochemical properties of the natural solids through which ARD flows toward groundwater and surface water.

8.2.3 Metal Leaching at Former Iron King Mine Property

Leaching of metals from tailings and other waste materials due to the effects of ARD or direct precipitation can impact surface water and groundwater. This section discusses metals leachability data for waste materials at the former Iron King Mine property, specifically the MTP. Evidence of impacts to surface water and groundwater in the vicinity of the former Iron King Mine property, including elevated metals concentrations, are discussed in subsequent sections. Figure 8-1 shows the locations of SPLP samples collected for metal leachability testing.

8.2.3.1 Synthetic Precipitation Leaching Procedure Data

The potential for metals leaching from the waste materials was evaluated using SPLP. This method targets the immediately leachable metals concentrations from the sample. The tests were performed with a pH of 5, which is the EPA standard leach solution pH for sites west of the Mississippi River. The metals concentrations in the SPLP leachate were compared to groundwater and surface water screening criteria to evaluate the potential for metals leaching from these media.

A total of 32 waste rock, tailings, and soil samples from the former Iron King Mine property were analyzed using the SPLP method. Results are summarized in Table 8-2. The most commonly detected metals included aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, and zinc. Note that because of elevated SPLP detection limits, nondetect values reported by SERAS in 2014 are not conclusive with regard to not exceeding screening criteria.

As the SPLP analysis targets the most readily leachable material, the forms of the leached portions of the samples are most commonly weathering products: evaporative salts (sulfates, carbonates) and oxidation products (oxides, hydroxides). The most common metals that form these materials are iron, aluminum, and manganese; these metals are therefore commonly found in SPLP leach samples. The discussion below focuses on arsenic, cadmium, copper, lead, and zinc, which are of primary interest at the Site.

- **MTP.** Nineteen SPLP tailings samples were collected in the MTP at eight locations, four of which were sampled over multiple depth intervals. SPLP leachate concentrations exceeded groundwater screening levels for arsenic in six samples collected from the upper 7 feet of the MTP. Three of these samples also exceeded screening levels for cadmium and zinc. Only one sample exceeded a surface water screening level for copper, and all lead SPLP analyses for MTP samples were below the detection limit. The upper portion of the MTP is acidic, based on the paste pH of 2.2 in the shallow sample at location IKJ-583, which is one of the samples that exceeded SPLP standards (Table 8-2). The acidic conditions of the upper portion of the MTP indicate more enhanced leaching is taking place near the surface. At greater depths, the tailings are not in regular contact with oxygenated leaching water, and therefore remain reduced with primary mineralogy intact. The results suggest that the exposure of the tailings to oxidation has been limited to the near-surface.
- **Small Tailings Pile.** Four tailings samples were collected at three locations for SPLP analysis prior to removal of the Small Tailings Pile in 2011. All four exceeded the screening level for arsenic, and one of these samples also exceeded either surface water or both surface water and groundwater levels for copper, cadmium, and zinc. Because the Small Tailings Pile has been removed, it no longer has the potential to produce ARD.
- **Waste Rock in the Former Mineworks Area.** Five samples of waste rock from the mine workings were collected for SPLP analysis at four locations. Cadmium, copper, and zinc screening levels were exceeded in the two samples collected at location IKJ-522 (0 to 2-foot depth, and 4- to 7-foot depth). No exceedances were found in the remaining samples.
- **Former Fertilizer Plant Area Soil.** Four soil samples were collected at three locations for SPLP analysis, with two exceeding screening levels for arsenic.

8.2.3.2 Fate and Transport of Leached Metals

Once leached from tailings or other materials, geochemical processes affect the fate of the metals dissolved in natural vadose zone materials, groundwater, and surface water. These processes include precipitation of minerals (such as oxides, hydroxides, or carbonates), or adsorption to soil mineral surfaces (most commonly on iron oxide/hydroxides and clay minerals). Adsorption or precipitation reactions may maintain dissolved metals concentrations at very low levels and attenuate their concentrations as impacted groundwater (or surface water) migrates away from source areas. These processes can be affected by solution conditions including pH, redox potential, ionic strength, and ionic composition of the water source.

Trace metals that exist as negatively charged oxyanions (for example, arsenic, molybdenum, and vanadium) will adsorb to a greater extent at low pH, whereas positively charged cationic metals (such as copper, lead, and zinc) will show greater adsorption at higher pH. Redox potential is important for the case of the most common adsorbent, iron oxides. These solids are only stable under oxidizing conditions; when redox conditions act to reduce iron, these solids will not form and iron will tend to be stable in solution rather than in a solid form. Without the iron oxide adsorbent present, there is diminished mineral surface for trace metal adsorption to occur. Some portions of the deeper tailings have displayed reducing conditions, characterized by green to black material and the absence of lighter-colored iron oxides (for example, MTP-MW01). Iron oxide minerals are evident both in oxidized areas of the tailings piles, and in the natural soils and sediments. Their overall distribution in the subsurface is not well characterized, but typically they are more abundant in the more preferred water flow paths and less so in other areas. This leads to a variable distribution of iron oxides and their adsorbed species.

Concentrations of trace metals exceeding SPLP screening limits were measured only in the top few feet of the tailings among the samples analyzed. However, there is no physical evidence of a lack of infiltration pathway through the tailings and into the underlying soil. Although the ABA data clearly show the potential for acidic, metal-rich drainage, the amount of ARD generated has been small enough under historical conditions that no strongly acidic waters have been detected in samples collected thus far. This is likely the result of the combination of detectable NP in historical tailings samples and the documented NP of the surrounding natural materials.

The groundwater data (Section 7.6.1) provide evidence that these transport processes (adsorption, precipitation, and attenuation) have impacted metals mobility. The flooded underground mine workings and wells completed within the Hickey Formation, beneath and downgradient of the MTP, are clearly impacted by elevated sulfate. However, although arsenic, lead, and other metals are elevated in the flooded underground workings, their concentrations are lower in the Hickey Formation beneath the MTP and decrease downgradient of the MTP (Figure 7-48). Arsenic concentrations in the shallow wells immediately downgradient of the MTP (MW-07S) only slightly exceed the MCL, and further downgradient (GW-999945), arsenic and lead concentrations do exceed MCLs, despite elevated sulfate at those locations.

In addition, in contrast to the Hickey Formation, sulfate concentrations in the bedrock monitoring wells near Iron King Mine are not elevated, suggesting limited migration of ARD impacts within the fractured bedrock.

8.2.4 Surface Water Transport at Former Iron King Mine Property

Surface flows from the former Iron King Mine property have carried various mine wastes, contaminated soil, and ARD downstream via the Chaparral and Galena Gulch drainages. Surface water and sediment data confirm that the following surface water transport mechanisms have occurred:

- Direct release and redistribution of mine waste during historical operations
- Erosion and deposition of mine waste or contaminated soils
- Discharge of metals through ARD mechanisms
- Precipitation and dissolution reactions, providing a flux of contaminants between surface water and sediment

8.2.4.1 Erosion and Transport

During high intensity rainfall events, precipitation that runs off unvegetated mine waste piles and areas of dispersed mine waste at the former Iron King Mine property has resulted in erosion and transport of contaminants with subsequent deposition of contaminants downstream. Mine waste or contaminated soil is also eroded from existing areas of deposition, such as the MTP tailings found in Chaparral Gulch, which can subsequently be transported downstream.

The highest (re)deposition rates for suspended particles are expected in areas where water velocity decreases. This includes the areas inside of bends, impoundments, immediately upstream of dams, immediately upstream of narrowing within the drainage/streambed, and immediately downstream of widening within the streambed or confluences.

Chaparral Gulch

Chaparral Gulch extends across the northern portion of the former Iron King Mine property and receives runoff from source areas at the property; specifically, the gulch receives runoff from the majority of the MTP (with the exception of the extreme southern portion of the MTP, which drains to Galena Gulch), the NAI Operations area, the former Glory Hole, areas north of the MTP, and the MTP Blow Out Path. Several stormwater retention ponds are used to control surface water flow on/from the MTP. Although these ponds do hold water for a portion of the year (for example, during heavy rains associated with monsoon season), they are normally dry (EA, 2010).

As presented in Table 7-3, the tailings in the MTP are predominantly composed of (at least 90 percent) fine particles (clay- and silt-sized particles) and sand. At moderate flow velocities (in the range of 2 to 3 feet per second), fine-grained particles and sand would be readily transported within the stream, or even eroded (Hjulström, 1939). The MTP 1964 Blow Out surface on the southeastern slope of the upper pile is steep, heavily eroded, and is subject to continued heightened erosion. Slopes on other portions of the east side of the MTP are also very steep and display evidence of erosion. The potential for erosion of the MTP, and subsequent transport of eroded soil and tailings into Chaparral Gulch is likely higher than for other portions of the property given these factors and the lack of vegetative cover on the MTP.

The former Small Tailings Pile, when present, was not located within the Chaparral Gulch 500-year floodplain interpreted from the flood study drawings (Cardno, 2014). During the Phase 1 RI in 2008 to 2009, EA observed there were no stormwater controls mitigating surface water migration from the Small Tailings Pile to Chaparral Gulch, and much of the area was devoid of vegetation (EA, 2010; E & E, 2012).

East of Highway 69, between the mine and the smelter property, Chaparral Gulch and the blow out path have been impacted by the MTP slope failure as well as fluvial transport of tailings from the mine property both well-before and after the blow out. Mine-impacted material has likely mixed with, and been diluted by, alluvial material from upgradient or non-mining-related sources in the Chaparral Gulch drainage basin. For example, a large amount of alluvium has been recently deposited in Chaparral Gulch, forming a widening floodplain between Highway 69 and Third Street, and filling in the culvert running beneath Third Street (see photographs in Appendix A). Long-time residents in the area communicated to EPA that the surface of Chaparral Gulch at Third Street used to be 6 to 10 feet lower 20 to 30 years ago.

Flows in Chaparral Gulch adjacent to (north of) the former Iron King Mine property were estimated to be in the range of 5,100 cfs for the 100-year return event based on a recent flood hazard study (Cardno, 2014). Water velocities within the flood channel were estimated to be up to 13 feet per second for this event. These velocities would be capable of eroding and transporting gravels and potentially coarser materials in the reaches with higher velocities.

Surface water data are not available from Chaparral Gulch upstream of the former Iron King Mine property, but surface water data for Chaparral Gulch downstream of the former Iron King Mine property indicate that total metals often exceed screening levels (Figures 7-42 through 7-47). For example, total metals concentrations from SWD-01 (on Chaparral Gulch just upstream of Highway 69) and SWD-02 (on Chaparral Gulch downstream of Third Street), which were both sampled in 2014 during a storm event, have concentrations of most metals above screening levels.

Sediment data, presented on Figures 7-37 through 7-41, demonstrate that the concentrations of the primary COIs in upstream reaches of Chaparral Gulch were much lower than concentrations detected in, and adjacent to, the former Iron King Mine source areas. Concentrations of the primary COIs exceeded screening levels in most of the downstream portions of Chaparral Gulch. These results indicate that metals from the former Iron King Mine property have been transported down Chaparral Gulch.

A detailed discussion of the Tailings Floodplain formation and deposition of materials in Chaparral Gulch is presented in Section 8.4.

Galena Gulch

Galena Gulch transects the southwestern portion of the mine property, adjacent to the former Mineworks area and the former Fertilizer Plant area, and flows south-southeast toward the Agua Fria River. Galena Gulch receives runoff from the former Mineworks Area and a small portion of the lower MTP. As presented in Table 7-2, the MTP is predominantly composed of fine particles and sand. Two of the primary Iron King Mine shafts (Shafts 1 and 5) and associated waste dumps are located along bedrock benches and adjoining slopes of Galena Gulch in the area south of the former Fertilizer Plant (Figure 2-1). Much of the downgradient channel of Galena Gulch is largely devoid of sediment, as it lies on the surface of scoured bedrock (CH2M, 2013). As discussed in Section 5.3.3, no flow monitoring has been conducted on Galena Gulch, and thus peak flows in the gulch are not known.

Surface water concentrations were generally lowest at the furthest upstream sample location and highest in the drainage ditch emanating from the former Mineworks area (Figures 7-42 through 7-46). These data indicate inorganics are mobilized from the former mine property during storm events.

Sediment data, as presented on Figures 7-37 through 7-41, indicate generally low metals in sediment in Galena Gulch upstream of the former Iron King Mine. Metals concentrations in sediment downstream of the mine are elevated. These results indicate that metals have been transported down Galena Gulch.

8.2.4.2 Discharge of Acid Rock Drainage

ARD processes result in the discharge of dissolved metals, sulfate, and acidic water to surface water drainage basins, namely Chaparral Gulch and Galena Gulch. Sulfate in surface water provides a clear indication of areas with ARD-related impacts. Unlike low pH, which can be neutralized by NP present in soils, and trace metals, which can be attenuated by adsorption to soil minerals, sulfate is a relatively conservative indicator of ARD. Sulfate concentrations elevated above background demonstrates that sulfides have been oxidized along the flow path.

As discussed in Section 7, four surface water samples collected within the former Iron King Mine property were analyzed for sulfate. The maximum sulfate concentrations (up to 27,000 mg/L) were detected in water samples collected from the retention ponds or impoundments on top of and at the base of the MTP, which indicates that the retention ponds in the immediate vicinity of the MTP are impacted by ARD. Low pH values were measured in the retention ponds (for example, the pH equaled 2.5 at sample location IP-1 in a retention pond on the lower MTP). Copper, lead, zinc, and other metals were detected above screening levels in water samples collected from the retention ponds. Both total and dissolved zinc, lead, and copper were detected at levels well above screening levels within the MTP as shown in Tables 7-17 and 7-18 and on Figures 7-42 through 7-47. These data all indicate localized impacts from ARD.

The presence of sulfate in the groundwater and the high AP of the tailings indicate that despite the current near-neutral pH and low observed trace metal concentrations, if the NP were to be used up over time, and the pH decreased sufficiently, adsorption could be affected and arsenic could be transported into the Hickey Formation. Under these conditions, adsorbing minerals such as iron oxides could be partially dissolved under low pH conditions, causing release of arsenic and other adsorbed trace elements. Cationic trace metals such as cadmium and lead would also be less readily adsorbed at a lower pH.

8.2.4.3 Transformation During Transport

Metals, sulfate, and acid products of ARD generated in the MTP area have entered the subsurface by mechanisms discussed above. The flux of seepage is small compared to the overall groundwater flux beneath the MTP area and downgradient, so dilution occurs during transport. The lack of strongly acidic pH and elevated metals concentrations in groundwater are evidence that NP has acted to neutralize the pH and metals have been attenuated by adsorption to mineral phases, most commonly iron oxides and hydroxides. These processes tend to neutralize pH, partition most of the dissolved metal mass to solid form, and dilute concentrations. The solid forms may continue to be transported downstream either as suspended fine-grained solids or as resuspended larger particles during heavy flow periods. More specifically, the key transformations are as follows:

- Acidic water is partially buffered by higher pH waters and native soil.
- Some of the dissolved iron and manganese oxidize, and form hydroxide precipitates.
- Trace metals adsorb to hydrous metal oxides and other minerals present in suspended form and/or in the channel bed.
- Metal and sulfate concentrations may be lowered as site runoff is mixed with flow from lower-concentration waters from tributaries and fresh rainfall.
- Coarse materials suspended in the flowing creek settle to the channel bottom in lower-velocity reaches.
- Precipitates or natural materials containing adsorbed metals that have settled to the channel bottom can redissolve or become resuspended, providing a flux of contaminants between sediment and surface water. These materials can be mobilized downstream during high rainfall and runoff events, potentially resulting in elevated metals concentrations in surface waters.

8.3 Former Humboldt Smelter Property Contaminant Release and Transport Mechanisms

This section summarizes the contaminant release and transport mechanisms specific to the former Humboldt Smelter property. Release mechanisms specific to the former Iron King Mine property are discussed above in Section 8.2.

8.3.1 Contaminant Release during Historical Operations

Contaminant releases that occurred during historical operations at the former Humboldt Smelter property are summarized below. This section focuses on the processes that would have occurred during operations. Contaminant disposal and release processes that occurred during historical operations included:

- Emissions from the smelter stacks
- Dust emissions during operations
- Discharge of tailings to Chaparral Gulch
- Discharge of tailings to the Smelter Swale
- Generation and placement of slag from operation of the smelter
- Placement of zinc and aluminum dross
- Placement and dumping of tailings along the Agua Fria River (early precursor operations)

8.3.1.1 Smelter Stack Emissions

Smelter stack and dust emissions that occurred during 4 decades of smelter operations distributed contamination both on- and off-property. Considering typical smelter operations for the time, the stack(s) would have vented airborne gaseous and particulate flux and superheated air from the reverberating and blast furnaces, as well the converters, which heated and further processed more-concentrated materials after the blast or reverberatory furnaces to further-purify the metal product. Particulates of ash and metals-laden minerals would have risen with the heated air in the stacks. In addition, metals with sufficiently low boiling points could have been vaporized and then recondensed as they rose and cooled.

Unlike tailings and other remaining waste materials at the Iron King Mine and Humboldt Smelter, the smelter stack emissions themselves can no longer be sampled directly as stack operations ceased almost 80 years ago. The concentrations of metals in the stack emissions therefore cannot be known. The Humboldt Smelter stack is short (less than 150 feet) as compared to stacks at modern smelters, which may have stacks of 500 to 1,000 feet. This bodes for lesser particulate travel distance prior to falling out of the air, as compared to modern-day smelters.

While in principle historical emissions and particulate fallout patterns could have been modeled, there is insufficient information (such as material content, temperature, emissions flux, operation timing and duration, and actual numbers and positions of stacks, etc.) for such modeling to be conducted with a useful degree of certainty; therefore, this approach was not pursued for the purposes of the RI. However, the data presented in Section 7 from residential soils north of the smelter indicate that any aerial deposition plume boundary (that is, fallout distance) for stack emissions did not exceed about 0.5 mile and may have been less. The data show that even inside the APSI at its periphery, the soils in residential screening areas (see Section 7.3) have low levels of lead, mostly characteristic of background. Areas where levels of lead in residential soils exceed the background concentration (about 35 mg/kg), while they follow a sporadic pattern, are contained within this short distance from the smelter.

As has been discussed, lead concentrations in residential soils are affected by a variety of non-site and site sources (not only potential historical stack emissions) and these vary from property to property. The aforementioned conclusion about the fallout distance based on a general area encircling occurrences above lead background must therefore be considered in an overall sense.

The smelter stack emissions, along with dust emissions from the former Iron King Mine property, are discussed in more detail in Section 8.5.1, which describes aerial dispersion of contaminants sitewide.

8.3.1.2 Tailings Discharge

A brief discussion of historical tailings placement in the Smelter Tailings Swale and Chaparral Gulch during active operations is presented in this section; post-operational and ongoing surface water erosional processes are discussed in Section 8.3.4. A comprehensive overview of the materials and processes that contributed to the formation of the Tailings Floodplain is presented in Section 8.4.

Ore concentration processes were used to produce higher-grade copper concentrates to feed the smelter. Tailings from this process were discharged to Chaparral Gulch and were impounded behind the Chaparral Gulch Dam (Figure 2-2). As discussed in Section 2, the date of the dam construction is not known, but based on the Cultural Resource and Historic Building Survey (Appendix B), it was likely built early in the 1900s.

During the initial period after dam construction, the elevation of the tailings upstream of the dam was likely significantly below the crest of the dam. This would have allowed for ponding of surface water behind the dam. During large storm events, retention of water behind the dam would have reduced the amount of tailings erosion. As the level of tailings and materials from upstream sources rose over time, the erosion of the tailings from upstream of the dam to Lower Chaparral Gulch would have increased. Although it is not known what the elevation of the tailings was upstream of the dam when the smelter was shut down in 1937, an aerial photograph taken in 1940 of the former Humboldt Smelter property (Appendix C) indicates that the Tailings Floodplain was present at that time, and hence, a potentially substantial amount of material had accumulated behind the dam. It is possible that erosion of tailings from the Tailings Floodplain to the Chaparral Gulch below the dam occurred to some degree during high-flow events at the time the smelter closed in 1937 due to decreased storage capacity behind the dam. However, the degree of erosion would depend on the size of the storms that occurred in relation to the available storage capacity behind the dam at the time of the storm events.

The Smelter Tailings Swale is a bowl-like formation located topographically lower and west of the Smelter Plateau. During active operations, this area also was used to store or dispose of tailings.

The tailings were stored behind a berm visible across the bottom of the swale (Figure 2-2). Operational timing of the use of this tailings disposal impoundment is not specifically known, but would have coincided with active smelter operations. Activity also could have occurred in the period between 1942 and 1945 when tailings were being reworked by C.H. Dunning for metal recovery, as described in Section 2.3.3.1. The 1940 aerial photograph (Appendix C) shows that the berm containing this impoundment had failed in at least one location prior to 1940 and had released tailings into the Chaparral Gulch Tailings Floodplain.

The peak and continuous production period of the smelter ended in 1923, 15 years before its final closure (after several intermittent inactive periods) in 1937. Therefore, it is almost certain that the Smelter Tailings Swale was being utilized as a tailings impoundment well before 1923 and perhaps as early as 1906 to 1910, when the smelter was rebuilt after the Val Verde smelter fire and then significantly expanded (see operational history discussion in Section 2.1.3). Since there are no photographs of the Smelter Tailings Swale in the earlier years, however, it is not possible to determine precisely when – or in particular, how early – the blow out occurred that discharged smelter tailings from the swale impoundment into the floodplain. Even prior to the blow out, tailings and wastewater discharges may have occurred from the smelter swale into the floodplain from earlier small retention ponds or swale impoundment overflows. This history and its relationship to the formation of the Tailings Floodplain is further discussed in Section 8.4.

8.3.1.3 Slag and Dross Placement

The former Pyrometallurgical Operations area is where the majority of the smelting operations occurred (described in Section 2.1.3.2). Pyrometallurgical operations resulted in the generation of smelter slag, a compilation of semi-consolidated and monolithic vitrified material. The primary smelter slag pile that remains on the former Humboldt Smelter site is located within the eastern side of the property, with a smaller satellite pile on the Smelter Plateau to the south. The slag deposits have formed a steep bluff overhanging the Agua Fria River, and slope failures have occurred in some areas. Erosion of slag into the Agua Fria River is also likely.

After closure and dismantling of the smelter operations, a large quantity of zinc and aluminum dross was imported in the late 1950s and early 1960s for reprocessing to recover the zinc and aluminum. The dross operations continued until 1970. The zinc dross was a waste material consisting mostly of flue dust and smelter skimmings imported from several California die-casting plants, whereas the aluminum dross was shipped from Texas (ACS, 2008) (see Section 2.3.3 for more detail). The dross was stockpiled on the former Humboldt Smelter property for processing. The dross is generally fine-grained and is susceptible to erosion via stormwater discharges (Section 8.3.4) and wind erosion (Section 8.5). As presented in Table 7-3, the total fines content (silt plus clay) for dross samples ranged from 19 to 89 percent.

Two samples designated as sediment were collected adjacent to the Agua Fria River near the eastern boundary of NR11 (locations OW-20 and OW-21). These samples were collected in an area where EPA observations indicate that dross mixed with slag extends down to the Agua Fria River (see Appendix A). The concentrations of COIs exceeded screening levels; the maximum copper concentration in sediment was detected at OW-20 (8,030 mg/kg). The very high aluminum concentrations (110,000 and 52,800 mg/kg in OW-20 and OW-21, respectively), moderate arsenic concentrations (163 and 181 mg/kg), and moderate iron concentrations (29,100 and 24,500 mg/kg) were more characteristic of the dross than slag materials (compare Table 7-16 with Tables 7-11 and 7-12). Concentrations of arsenic, lead, copper, and zinc in a sediment sample within the Agua Fria River (AF-5) located downstream of OW-20 and OW-21 also exceeded screening levels, indicating local site-related impacts; however, concentrations were much lower.

8.3.1.4 Agua Fria Tailings Pile Placement

The Agua Fria Tailings Pile is located along the Agua Fria River just downslope of the former Chaparral Gulch Shaft (Figure 2-2). As discussed in Section 2.1.3.5, the Chaparral Gulch Shaft mining operation provided ore to the Agua Fria Ore Mill and Smelter in the 1870s and 1880s (ACS, 2008). The Agua Fria Tailings Pile is likely the result of tailings that were tremied or slurried from this predecessor mining and milling operation. Because of the proximity of these tailings to the Agua Fria River, some releases of tailings may have occurred during operation. These tailings are a potential ongoing source of contamination to the Agua Fria River via erosion.

8.3.2 Acid Rock Drainage at the Former Humboldt Smelter Property

This section discusses indicators of ARD generation potential using ABA, and site-specific analysis of factors influencing the generation of ARD from waste materials at the former Humboldt Smelter property, including:

- Tailings
- Dross
- Slag

Leaching of rainfall and runoff through sulfidic waste materials at the former Humboldt Smelter property, as at the former Iron King Mine property, will generate ARD and contribute sulfate to surface water and shallow groundwater. If geochemical conditions do not act to neutralize acid and attenuate metals released by this process, then shallow groundwater and surface water may be subject to more acidic conditions and elevated metals concentrations as well.

The mechanisms of formation, fate, and transport of ARD from contaminant sources at the former Iron King Mine property are discussed in Sections 8.2.2.1 and 8.2.2.3. Those same mechanisms also apply to the ARD generated from contaminant sources at the former Humboldt Smelter property, and as such are not discussed further here. Figure 8-1 shows the locations of samples collected for ABA metals leachability testing and SPLP metals leachability testing at the former Humboldt Smelter property. The data from these tests are summarized below.

The general principles of ABA are discussed in Section 8.1.2. A total of 12 samples associated with source materials at the former Humboldt Smelter property were analyzed for ABA properties, as follows:

- **Tailings Swale.** The two tailings samples from the Smelter Tailings Swale had NNP values of -49 and -56, indicating both tailings samples are acid generating. Paste pH values range from 3.6 to 5. By contrast, the two non-tailings samples collected from this area showed positive NNP values of 26 (Hickey Formation) and 229 (Colluvium), indicating both are net neutralizing, consistent with other natural materials in the area. The consistently positive NNP of the natural materials in the area, which are much greater in volume than tailings, strongly suggests that although the tailings are net acid generating, there is sufficient NP in the native material to maintain pH-neutral conditions and prevent migration of acidity away from the source areas.

- **Dross.** The five samples of dross from the former Pyrometallurgical Operations area all showed positive NNP (ranging from 57 to 88 kg $CaCO_3$/tn), indicating the dross is not acid generating. Paste pH values ranged from 7.2 to 8.35.

- **Slag.** The three smelter slag samples (one from the former Pyrometallurgical Operations area and two from the Smelter Plateau) had intermediate NNP values (-1 to 16 kg $CaCO_3$/tn) and NPR values that range from approximately 1 to 5, indicating the slag has uncertain but potentially weak acid-generating characteristics. Paste pH values ranged from 7.3 to 7.9.

Both of the tailings samples collected from the Smelter Tailings Swale show acid-generating characteristics, consistent with Iron King Mine samples. Samples from the tailings swale representing natural materials were net neutralizing. Unlike the Iron King Mine, the Humboldt Smelter property is not dominated by tailings, which are limited to the Smelter Tailings Swale area of historical discharge. The small volume of acid-generating materials compared to net neutralizing native materials indicates that acid mobility will be limited to the source materials themselves and will be neutralized as it migrates away from these areas.

8.3.3 Metals Leaching at Former Humboldt Smelter Property

Leaching of metals from tailings and other waste materials due to the effects of ARD or direct precipitation can impact surface water and shallow groundwater. This section discusses metals leachability data for waste materials at the former Humboldt Smelter property, including:

- Tailings
- Dross
- Slag

Evidence of impacts to surface water and groundwater in the vicinity of the former Humboldt Smelter property, including elevated metals concentrations, are discussed in subsequent sections. Figure 8-1 shows the locations of samples collected for SPLP metals leachability testing.

8.3.3.1 Synthetic Precipitation Leaching Procedure Data

A total of 24 samples from the Humboldt Smelter area were analyzed using the SPLP method, which is described in Section 8.2.3. The discussion below focuses on arsenic, cadmium, copper, lead, and zinc, which exceed screening levels most frequently.

- **Tailings.** Nine tailings samples were collected for SPLP analysis, seven from the tailings swale (three locations) and two from the smelter property (one location). The smelter location showed exceedance of the screening level for arsenic (groundwater) and copper (surface water). Of the seven swale samples, two showed exceedance of groundwater and/or surface water screening levels for aluminum, copper, and zinc; one of these samples was from 10.5 feet bgs at STS-SB08. Surface water screening levels for cadmium were exceeded in three samples, including the 10.5-foot sample at STS-SB08. These results indicate that the tailings from the swale have the potential to leach metals at concentrations above screening levels.

- **Dross.** Eleven dross samples from eight locations were collected for SPLP analysis. Lead exceeded groundwater and surface water screening levels at the shallow sample from one location (HSJ-507). This same sample exceeded the surface water screening level for copper, and arsenic exceeded the groundwater screening level at both shallow and deeper samples (4 to 7 feet bgs) from this location. Three dross samples also exceeded surface water and groundwater screening levels for aluminum.

- **Slag.** Four SPLP samples were classified as smelter slag. SPLP leachate samples exceeded screening levels for arsenic, copper, lead, or zinc in two or more of the samples. The data indicate that slag has leachable trace metals that can be released to the native soils, with arsenic being the most consistently detected element in the samples collected thus far.

8.3.3.2 Fate of Leached Metals

The same general mechanisms govern the mobility and fate of leached metals from source materials at the former Humboldt Smelter property as those described in Section 8.2.3 for source materials at the former Iron King Mine property. The exceedance of screening criteria in the 10-foot SPLP sample from the Smelter Tailings Swale demonstrates that the erosional transport of tailings into the swale has created a stratified system over time where semi-oxidized tailings are present at depth. This is in contrast to what is observed at the MTP, where the deeper tailings have not been transported or exposed to air since they were discharged to the pile.

Overall, the native soils surrounding the swale area contain abundant iron oxides and other minerals that provide adsorbent surfaces for metal attenuation, though their distribution is variable as explained earlier for the former Iron King Mine property. In general, leached metals from the tailings and dross will decrease in concentration as the leachate moves downstream and toward the water table due to adsorption to these native materials. However, accurate prediction of groundwater and surface water concentrations is not possible given the data density and the known variability of mineral distribution and hydraulic properties.

8.3.4 Surface Water Transport at Former Humboldt Smelter Property

Surface flows from source areas at the former Humboldt Smelter property have carried various smelter wastes, contaminated soil, and ARD downstream to Chaparral Gulch and the Agua Fria River. Surface water and sediment data confirm that the following surface water transport mechanisms have occurred:

- Direct release and redistribution of smelter waste during historical events
- Erosion and deposition of smelter waste or contaminated soils
- Discharge of metals through ARD mechanisms
- Precipitation and dissolution reactions, providing a flux of contaminants between surface water and sediment
- Evapoconcentration of metals due to repeated wetting and evaporation on tailings

See Section 8.3.1 for a discussion of direct release and distribution of waste during historical events. The other transport mechanisms are discussed in the following subsections.

8.3.4.1 Erosion and Deposition

During high intensity rainfall events, precipitation runs off unvegetated waste piles and areas of dispersed waste and contaminated soils at the former Humboldt Smelter property and has resulted in erosion, transport, and deposition of contaminants. Tailings and smelter waste or contaminated soil are also eroded from existing areas of deposition, such as the Smelter Tailings Swale and the Tailings Floodplain, which can be subsequently transported to Lower Chaparral Gulch and into the Agua Fria River. The deep erosional patterns in the Smelter Tailings Swale indicate that this is an area where substantial erosion has occurred and is likely to continue to occur in future storm events.

The highest (re)deposition rates for suspended particles are expected in areas where water velocity decreases. This includes the areas inside of bends, impoundments, immediately upstream of dams, immediately upstream of narrowing within the drainage/streambed, and immediately downstream of widening within the streambed or confluences. Erosion and deposition processes are described below for the primary surface waterways at the Site.

Chaparral Gulch

Chaparral Gulch receives runoff from the Smelter Tailings Swale in addition to upstream sources (including at the former Iron King Mine property) and flows directly through the Tailings Floodplain. Transport and deposition of materials from both the former Iron King Mine and Humboldt Smelter properties have resulted in the deposition of tailings in the Tailings Floodplain on the Humboldt Smelter property. In the Smelter Tailings Swale, water erosion in preferential pathways has cut gullies as deep as 15 feet through the material behind the berm. A detailed discussion on the formation of the Tailings Floodplain is included in Section 8.4.

As discussed in Section 5.3, the portion of Chaparral Gulch upstream of the former Humboldt Smelter property only flows during infrequent episodic high rain events. Stream stage measurements were recorded at two locations approximately 70 feet apart along the Lower Chaparral Gulch downstream of the Chaparral Gulch Dam during July through October 2014 as part of the data gap phase of the RI (Lockheed Martin SERAS, 2015). The observed flow velocities ranged from 1.41 to 6.45 feet per second. Peak flows during this monitoring period were calculated to range from 4 to 290 cfs.

As presented in Table 7-3, material in the Smelter Tailings Swale is predominantly composed of fine particles and sand (at least 66 percent); the Tailings Floodplain also is predominantly fine particles and sand (at least 54 percent). At the flow velocities observed during the stream stage measurements in 2014, fine-grained particles and sand would be readily transported within the stream, or even eroded (Hjulström, 1939). Thus, tailings in the Smelter Tailings Swale are readily transported to the Tailings Floodplain. Little or no storage capacity remains behind the dam because of the accumulation of tailings and alluvium, and the active channel of Chaparral Gulch continues to run through the Tailings Floodplain. Therefore, tailings and sediment in the Tailings Floodplain can continue to be transported into Lower Chaparral Gulch and subsequently into the Agua Fria River. The potential for erosion of the Tailings Swale and Tailings Floodplain into Chaparral Gulch is likely higher given the lack of vegetative cover on the tailings.

A comparison of surface water samples collected during storm flow conditions and baseflow conditions provides evidence that erosion of tailings and contaminated soil or sediment is occurring from the Smelter Tailings Swale and Tailings Floodplain. Samples collected between July and October 2014 using dedicated sampling devices designed to capture storm flows (SWD sample designation) had high turbidity readings of 585 to greater than 1,000 NTU. Total metals concentrations in stormwater samples collected at the edge of the Smelter Tailings Swale (SWD-03) and immediately upstream of the dam (SWD-04) were an order of magnitude or more greater than concentrations in samples collected near the dam under baseflow conditions in May 2014 (DAM-SW01 and DAM-SW02) (see Table 7-17 and Section 7.5.3).

Elevated concentrations of metals were detected in surficial sediment throughout Lower Chaparral Gulch as presented on Figures 7-37 through 7-41. The depth to bedrock was measured as 3.5 to 4.5 feet from the base of the dam to 600 feet downstream (DAM-SED01 to DAM-SED04), greater than 5 feet near the Lower Chaparral Gulch tailings deposit at the “elbow” where Chaparral Gulch turns north (DAM-SED05), and 0.5 to 2.0 feet downstream (DAM-SED06 to DAM-SED08). Elevated metals concentrations were detected in all subsurface sediment samples in Lower Chaparral Gulch (arsenic up to 780 mg/kg and lead up to 1,350 mg/kg at DAM-SED03). The Lower Chaparral Gulch tailings deposit near DAM-SED05 is likely associated with precursor operations; however, the distribution of sediment with elevated concentrations throughout Lower Chaparral Gulch indicates that wastes likely also migrated to this downstream reach of the gulch from upstream sources.

Agua Fria River

Stormwater runoff flows directly from portions of the former Humboldt Smelter property to the Agua Fria River. This includes runoff from the northeast areas of the former Humboldt Smelter property (where dross and slag piles are present). The Agua Fria Tailings Pile associated with an early predecessor smelter is also located adjacent to the Agua Fria River, just upstream of the confluence with Chaparral Gulch. Chaparral Gulch and Galena Gulch are intermittent surface water features. Contaminant transport of particulates (and dissolved-phase contaminants) via surface water occurs primarily during periodic high rainfall events.

As discussed in Section 7.5.4, total metals concentrations in the Agua Fria River surface water were generally less than screening levels above the confluence with Chaparral Gulch. One exception was that total concentrations of several metals were above screening levels at location SWD-08. This was one of the locations with a dedicated sampling device used to monitor storm flows (Lockheed Martin SERAS, 2015), and the turbidity of the sample was greater than 1,000 NTU, indicating the Agua Fria River was carrying a large sediment load during the storm event. Location SWD-08 is adjacent to the former Pyrometallurgical Operations area (NR11), near an area of elevated sediment concentrations and where

EPA observations indicate loose, crumbling slag mixed with dross extends down to the edge of the Agua Fria River (Photograph 32 in Appendix A). However, metals concentrations in other surface water samples collected near this location were below screening levels. Because no upstream surface water samples were collected during storm events, it is unclear whether the surface water concentrations detected at SWD-08 are a result of the erosion of dross, slag, or smelter-impacted soils and/or a result of non-smelter-related sources such as upstream agricultural uses or stormwater runoff.

Concentrations of COIs in surface water were elevated at the confluence with Chaparral Gulch, compared with concentrations at upstream sampling locations in the Agua Fria River, but were orders of magnitude lower than concentrations detected in Chaparral Gulch. Total copper, iron, lead, and zinc exceeded screening levels in surface water at locations up to 2,500 feet downstream of the confluence. However, concentrations of the primary COIs were below screening levels in the furthest downstream locations in the Agua Fria River, indicating that surface water impacts were localized.

A comparison of sediment data in the Agua Fria River with concentrations elsewhere on the Site shows that concentrations of the primary COIs in sediment in the Agua Fria River were generally low upstream of the former Humboldt Smelter property, low to slightly elevated adjacent to the Site, and remained low to slightly elevated below the confluence with Chaparral Gulch, as shown on Figures 7-37 through 7-41. The highest concentrations were detected in sediment samples near the former Humboldt Smelter property source areas and near the confluence with Chaparral Gulch. Erosion and deposition of mine- or smelter-impacted material is a likely pathway for the sediment contamination, in addition to placement/dumping of material at the slag and dross piles and the Agua Fria Tailings Pile. Concentrations of the primary COIs were either below screening levels or marginally exceeded screening levels in sediment samples from the furthest downstream locations, indicating that site-related sediment impacts are localized. Upstream sediment samples, along with the sitewide soil background dataset, indicate there are also naturally occurring sources of arsenic and copper within the Agua Fria River sediment at concentrations exceeding screening levels.

8.3.4.2 Discharge of Acid Rock Drainage

ARD processes can result in the discharge of dissolved metals, sulfate, and acidic water to surface water bodies, including the Agua Fria River. Sulfate in surface water provides a strong indication of areas with ARD-related impacts. As discussed in Section 7, multiple surface water samples collected within or adjacent to the former Humboldt Smelter property have been analyzed for sulfate.

The samples collected in Chaparral Gulch contained sulfate concentrations at levels that indicate impacts from ARD (Figure 7-47). Sulfate concentrations were at or above 1,000 mg/L in surface water samples collected from Chaparral Gulch in the Tailings Floodplain, at the dam, and within 450 feet of the dam (Figure 7-47 and Table 7-17). Aerobic water flowing through surficial and shallow-depth source material has likely caused oxidation of sulfides. As discussed in Section 7.5.3, low pH was measured in surface water samples within the Tailings Floodplain (pH was 2.9 at location CG-14), indicating generation of ARD. The pH measurements in the surface water downstream of the dam were near neutral during baseflow sampling (ranging from 6.3 to 8.2). The lowest pH (6.3) was measured just below the dam. The pH data indicate that, although ARD reactions are occurring in the material upstream of the dam, the quantity of ARD generated is small relative to the NP of native sediments.

Sulfate and pH data indicate that site-related impacts diminished with distance from the dam. The sulfate concentration decreased to 350 mg/L at a distance of 650 feet downstream of the dam (SWD-07), and the sulfate concentration was low (53 mg/L) in the baseflow sample collected at the confluence with the Agua Fria River (DAM-SW06). The pH measurements consistently increased with distance downstream of the dam, with the maximum pH of 8.2 measured at the confluence with the Agua Fria River (DAM-SW06).

Sulfate was below 100 mg/L in all samples collected in the Agua Fria River, more than an order of magnitude below concentrations detected in the Tailings Floodplain and Lower Chaparral Gulch. Dissolved metals were generally below screening levels in the Agua Fria River downstream of the confluence with Chaparral Gulch, although dissolved copper was above screening levels on at least one occasion in the Agua Fria River immediately below the confluence. The low sulfate and dissolved metals data in the Agua Fria River indicate that the transport of ARD has not significantly impacted the river.

8.3.4.3 Transformation during Transport

Metals, sulfate, and acid products of ARD generated in the Humboldt Smelter and Smelter Tailings Swale areas have entered the subsurface by mechanisms discussed above. The flux of seepage is small compared to the overall groundwater flux beneath the source areas and downgradient, so dilution occurs during transport. The lack of strongly acidic pH and elevated metals concentrations in groundwater are evidence that NP has acted to neutralize the pH and metals have been attenuated by adsorption to mineral phases, most commonly iron oxides and hydroxides. These processes tend to neutralize pH, partition most of the dissolved metal mass to solid form, and dilute concentrations. The solid and adsorbed forms may continue to be transported downstream either as suspended fine-grained solids or as resuspended larger particles during heavy flow periods. The specific transformations are listed in Section 8.2.4.3.

8.3.4.4 Evapoconcentration of Metals

Metals have concentrated on the surface of some areas of the tailings within the Smelter Tailings Swale and Tailings Floodplain during repeated cycles of wetting, capillary transport from below the surface, and evaporation – a process termed evapoconcentration. The result is formation of efflorescent salts (evident as a white crust) on the surface of tailings in the Smelter Tailings Swale and Tailings Floodplain (see photographs in Appendix A), and in the Lower Chaparral Gulch area of tailings just upstream of the confluence with the Agua Fria River. The concentration of lead in these salts exceeds 10,000 mg/kg.

Efflorescent salts are more soluble than the primary mineral phases from which they are derived. After formation, they can contribute elevated dissolved metal loads in first flush storm events (that is, in a larger storm event after a prolonged drier period) to downgradient surface water in Chaparral Gulch. While efflorescent salts can be seen sporadically throughout the smelter swale and the Tailings Floodplain, they are most prevalent and extensive in the location where smelter swale tailings fanned out into the floodplain, north of the main active channel of Chaparral Gulch through the floodplain.

8.4 Tailings Floodplain Formation and Properties

This section presents a summary and analysis of the formation processes that have contributed to the development of the Chaparral Gulch Tailings Floodplain. It includes a description of the floodplain formation based on historical information, aerial photographs, and site observations. It also includes a discussion of the Tailings Floodplain material properties, and an evaluation of the material contributions to the Tailings Floodplain based on the concentration of geochemical indicators diagnostic of Iron King Mine tailings compared to Humboldt Smelter tailings and natural sediments.

8.4.1 Development of the Floodplain

As discussed in Section 2, the Tailings Floodplain is defined as the area behind the Chaparral Gulch Dam (Figure 2-2) with historical accumulation of tailings and natural sediments. The floodplain extends from just upstream of the Smelter Tailings Swale to the dam.

Tailings were disposed to the Smelter Tailings Swale or directly to the Tailings Floodplain during the active years of the Val Verde and Humboldt Smelter operations (1899 to 1937; see Section 2). At least one breach of the Humboldt Smelter Tailings Swale containment berm had occurred prior to 1940 (the earliest available aerial photograph of this area; Appendix C). This tailings footprint in the Tailings Floodplain developed over time as storm events caused progressive migration of Humboldt Smelter tailings materials downslope toward Chaparral Gulch.

Upstream of the floodplain, activities at Iron King Mine are evident on aerial photographs from 1940 onward, with tailings impoundments constructed along a natural drainage that leads to Chaparral Gulch. Overflow from the impoundments outfalls during routine operations, minor breaches, and overflow during large precipitation events, along with drainage to Upper Chaparral Gulch from the ore processing facility and the mine workings, likely contributed mine waste to the main channel of Upper Chaparral Gulch and to the drainage confluence east of Third Street throughout the 1940s and 1950s.
In March 1964, a major event occurred in which a portion of one of the main tailings impoundments at Iron King Mine failed. Although most of the tailings were contained within a historical railroad berm immediately downstream of the impoundment, one former employee estimated that 5,000 tons of tailings moved beyond this berm into Chaparral Gulch (Kentro, 1964). None of the available historical documents provide substantive documentation regarding the actual volume of tailings eroded downstream. Tailings migrated downstream of the railroad berm, followed a path south of the upper gulch (near the location of the current JT Septic Facility) and along Third Street, and merged with Chaparral Gulch at Third Street.

In the Chaparral Gulch Tailings Floodplain, at the time of the 1940 aerial photograph, the area below the Smelter Tailings Swale and above the dam was a cottonwood/willow riparian forest. As mentioned above, at least one breach was visible in the Smelter Tailings Swale containment berm, although the tailings had not migrated very far below the breach. In Chaparral Gulch above the Smelter Tailings Swale, no significant riparian vegetation was visible, as discussed in the Riparian Evaluation Report (WestLand, 2009). The 1953 and 1964 aerial photographs show a progression of downslope movement of tailings from breaches in the Smelter Tailings Swale containment berm; the 1964 photograph shows the beginning of encroachment on the riparian forest.

As of 1964, there was still no apparent riparian zone in Chaparral Gulch in the reach from Third Street to above the Smelter Tailings Swale (Middle Gulch). This portion of Chaparral Gulch appeared to contain substantial areas of tailings in the 1964 and earlier photographs. The presence of tailings during this period may explain the lack of riparian vegetation during this timeframe.

From 1970 through 1980, there was considerable movement of sediments and tailings into the area above the Chaparral Gulch Dam. This was accompanied by a loss of riparian vegetation. The 1992 aerial photograph showed that the riparian area above the dam was mostly gone, and the basin above the dam was filled with sediment. The Riparian Evaluation Report (WestLand, 2009) concluded:

- It is likely that much of the sediment filling the Tailings Floodplain was derived from higher regions in the Bradshaw Mountains and was transported by major flood events in Chaparral Gulch.
- The extensive amount of gravel in the sediments observed onsite could not have been derived from tailings material alone.

Based on these observations and the likely presence of tailings in the Middle Gulch in the earlier aerial photographs, it is likely that tailings in Chaparral Gulch derived from Iron King Mine activity would have been transported downstream toward the dam along with the natural sediments during the various storm events.

Although the Middle Chaparral Gulch area upstream of the smelter swale was devoid of vegetation in the early aerial photograph record (1940 through 1964), it began to develop riparian vegetation after 1970. This may indicate that Iron King Mine tailings that had been present in this reach as of 1940 continued to migrate downstream with storm events in subsequent years and mixed with additional natural alluvial material from upstream sources. The transport of the cleaner alluvial material from upstream may have buried a portion of the Iron King Mine tailings deposited at an earlier time in the formation of the Tailings Floodplain, allowing improved vegetation growth in later years. It may also explain why there are locations in the Middle Gulch where material with elevated concentrations of lead and arsenic are present at deeper depths (5 to 10 feet deep) buried under cleaner sediments upstream of the Smelter Swale as shown on Figure 7-26 (for example, borings CH-SB20, CH-SB24, and CH-SB30).

Concurrent with the events described above, Humboldt Smelter tailings were being eroded from the Smelter Swale and impacting (removing) the riparian vegetation downstream from the Smelter Tailings Swale to the dam (1953 through 2003). The tailings eroded from the Smelter Tailings Swale appeared to form an alluvial fan into the Tailings Floodplain. This may have constricted the Iron King Mine tailings and upstream alluvial material to the more southerly edge of the Tailings Floodplain.

Stratigraphic units in the floodplain, reported in Section 7.2.3.1 and detailed in Appendix F, provide an approximate breakdown of contributing materials to this environment. The PFG and Brown Clay units represent older channel sediments that pre-date, and were relatively unaffected by, mine and smelter impacts. More recent channel deposits (UCD, HSCD, and LCD) represent mostly natural sediments carried into this area from upstream sources, but with mine and smelter waste materials combined in varying amounts. The Iron King Mine MTP tailings and Humboldt Smelter tailings and other smelter wastes have many similarities, but also some distinctly different properties that may be used to distinguish them. The tailings and natural sediment chemical properties played a role in labeling Humboldt Smelter tailings as “undisturbed” (largely unoxidized and retaining their chemical signature) and “reworked” (oxidized and moved out of their original deposition locations by flow events that may have contained Iron King Mine tailings).

The Tailings Floodplain is a complex alluvial deposition system that has developed approximately over the last 100 years. The depositional sequences described above provide a framework to understand the major processes that have occurred; however, the distribution of the sediment on a smaller scale is a complex interbedding of tailings, alluvium, and mixtures of both. In some areas, clean alluvium overlies previously deposited tailings, while in adjacent areas, tailings overlie and are interbedded with clean alluvium. Review of the boring logs and metals distributions in the Tailings Floodplain as presented in Section 7 provides a detailed description of the locations of tailings, alluvium, and tailings mixed with natural alluvial materials.

The sections below provide descriptions of the floodplain materials and their properties, and use chemical data to support the presence of Iron King Mine tailings along with Humboldt Smelter tailings and natural sediments in the floodplain.

8.4.2 Chaparral Gulch Material Properties

Samples from the Tailings Floodplain were collected and analyzed for ABA properties and SPLP analysis at several events between 2008 and 2014. The results are presented in Tables 8-1 (ABA) and 8-2 (SPLP), where they may be compared with the results from Iron King Mine and Humboldt Smelter (discussed separately in Sections 8.2 and 8.3).

8.4.2.1 Acid-Base Accounting Properties

Nineteen samples were collected from the Tailings Floodplain and analyzed for ABA parameters. Of these, 16 were classified as tailings (15 undisturbed and 1 reworked); the remaining samples included 2 UCD samples and 1 Brown Clay sample. Principles behind ARD and ABA parameters are discussed in Section 8.1. The sample results are provided in Table 8-1.

Of the 16 samples classified as tailings, 13 had NNP values less than -20 kg $CaCO_3$/tn and/or NPR values below 1, indicating the majority are acid-generating. This is consistent with the finding that all tailings samples from the Iron King Mine and Smelter Tailings Swale were acid-generating (Table 8-1). The most negative NNP value was -256 kg $CaCO_3$/tn, which was found in the reworked tailings sample, located close to the dam (DAM-SB05). One tailings sample had NNP greater than 20 kg $CaCO_3$/tn (net neutralizing), demonstrating that not all tailings samples are associated with acid generation. Because these floodplain samples may contain a mixture of tailings and natural sediments, some samples would be expected to show more neutral properties than the tailings samples from source locations. The samples showing net neutralizing values or in-between neutralizing and acid generating values are located in the Chaparral Gulch channel area upstream of the dam. These data suggest areas of the main channel where more vigorous intermixing of natural sediments and tailings has occurred and tends to result in more neutral conditions by combining tailings with the more neutral natural sediments. Surface water pH, sulfate, and metals concentration data are discussed in Section 8.3.4.

As expected, the Brown Clay was net neutralizing since this material was relatively unaffected by mine or smelter activity. Conversely, both UCD samples were acid-generating, showing the likely influence of Iron King Mine tailings in these channel deposits from locations upstream of the Humboldt Smelter area. Paste pH values ranged from 1.9 to 7.4, with both the lower and upper end of this range found in tailings samples.

8.4.2.2 Synthetic Precipitation Leaching Procedure Analysis

Fifteen samples were collected for SPLP analysis; 10 of these were designated as tailings, three were UCD samples, and one was Brown Clay. Results of SPLP analysis are provided in Table 8-2. Principles behind SPLP analysis and fate of leached metals are discussed in Section 8.2.3. Of the 15 SPLP samples, 2 exceeded either groundwater, surface water, or both screening levels for arsenic, cadmium, and zinc. One was a tailings sample and the other was a UCD sample. Copper screening criteria were exceeded in two samples – the same UCD sample and a different tailings sample. No sample exceeded lead screening levels. The remainder of the samples were nondetect for these four metals. Because of elevated detection limits described in Section 8.2.3, conclusions for these nondetect results could not be made.

8.4.3 Contributions to Tailings Floodplain Deposits

As described in Section 8.4.1, the Tailings Floodplain has developed over the past approximately 100 years as tailings were discharged directly to Chaparral Gulch, or were originally stored in the Smelter Tailings Swale, which breached its various containment barriers into the gulch. The smelter tailings made a gradual migration over time toward the Tailings Floodplain. During this same period, there is evidence of tailings from Iron King Mine also migrated to the Tailings Floodplain. Previous studies of the Tailings Floodplain (WestLand, 2009) have suggested that normal, periodic storm events have gradually pushed gulch sediments, including Iron King Mine tailings, downstream to the point where they are likely present in the Tailings Floodplain along with the former Humboldt Smelter property tailings. This section describes the use of geochemical indicators to identify the presence of Iron King Mine tailings in the floodplain.

Section 7 provided a detailed description of locations of elevated soil and sediment COI concentrations at the Site, including lead, zinc, and copper, as well as the ratio of lead to copper (Pb:Cu) and zinc to copper (Zn:Cu). These parameters were also reported in each floodplain stratigraphic unit (the units are also included in the discussion of floodplain development in Section 8.4.1). The metals are clearly elevated in tailings samples at both the former Iron King Mine and Humboldt Smelter properties compared to native soil and sediment samples. The Iron King Mine tailings are distinguished by the highest average concentrations of lead and zinc in the samples, whereas copper tends to be the dominant metal in the Humboldt Smelter tailings. Statistical treatment and a detailed evaluation of these data are provided in Appendix I.

As presented in Appendix I, a combination of metals concentrations and metal ratios was used to demonstrate a geochemical distinction between the Iron King Mine tailings and Humboldt Smelter tailings, along with natural materials in the area. Figure 8-3 shows lead concentrations, along with Pb:Cu and Zn:Cu ratios, plotted against zinc concentration for Iron King Mine tailings (solid lines around data groups) and Humboldt Smelter tailings (dashed lines around data groups). The lead concentration field for Iron King Mine tailings (upper right oval in the figure, labelled “Pb”) is distinct from the lead data of the Humboldt Smelter tailings, along with the Pb:Cu ratio data. This reflects the elevated lead and zinc (both consistently over 1,000 mg/kg) inherent in the Iron King Mine Tailings, resulting in these data plotting in the upper right of the figure. By contrast, the concentrations of these elements in Humboldt Smelter material are mostly in the 100s of mg/kg. Although the copper and Zn:Cu fields are also different between the two sources, this is mainly caused by the difference in zinc between the two, while copper is somewhat similar in range. Overall, the lead and zinc concentrations provide the most effective geochemical distinction between the two tailings sources.

A strong indication of source is evident when Iron King Mine tailings are compared in this manner to natural materials (Brown Clay, PFG, and Hickey conglomerate), making the chemical signature of the Iron King Mine tailings unique among all of the soil/sediment signatures around the Site.

The greater overlap between Iron King Mine tailings and the reworked Humboldt Smelter tailings collected in Chaparral Gulch, as shown on Figure 8-4, demonstrate the influence of Iron King Mine tailings in these deposits, consistent with the CSM of their formation. The movement of sediments and tailings downstream during storm events, effectively mixing the Iron King Mine tailings with the Humboldt Smelter tailings, produces the overlapping chemistry shown on Figure 8-4, compared to the greater separation evident on Figure 8-3. Concentration plots comparing Iron King Mine tailings to all other stratigraphic unit data are provided and discussed in Appendix I.

Based on examination of the concentration plots in Appendix I, it was determined that Iron King Mine tailings had the following unique attributes compared to the other material types, including Humboldt Smelter tailings:

- Lead concentrations were consistently greater than 1,000 mg/kg (other material types contained lower concentrations)
- Zinc concentrations were consistently greater than 1,000 mg/kg (other material types contained lower concentrations)
- Pb:Cu ratios were mostly greater than 6 (other material types had lower ratios)
- Zn:Cu ratios were mostly greater than 20 (other material types had lower ratios)

The tailings from Iron King Mine are a clear end-member for these four parameters (especially lead and zinc concentrations, and to a slightly lesser degree the two ratios) compared to the other material groups, and therefore a powerful tool to identify these tailings mixed with the other materials, including Humboldt Smelter tailings. Copper was not as useful as an attribute to distinguish Iron King Mine tailings from Humboldt Smelter tailings because the copper concentration ranges overlapped. Therefore, the Pb:Cu and Zn:Cu ratios were also slightly less useful than the simple lead and zinc concentrations to distinguish Iron King Mine tailings from Humboldt Smelter tailings, although the ratios were still useful.

Each of the samples for each of the material types was scored over a range of 1 to 7 for how closely they resembled Iron King Mine tailings, with 1 being best and 7 being worst. A score of 1 was given if both lead and zinc were greater than 1,000, indicating high confidence that the material was from Iron King Mine. A score of 2 was given if each of the concentrations was greater than 900, indicating that some mixing with materials not from Iron King Mine could have occurred. Scores of 3, 4, 5, 6, and 7 were given if the concentrations were greater than 800, 700, 600, 500, and 0, respectively. The range from 500 to 0 was not further broken-down because this encompasses the range of concentrations for Humboldt Smelter tailings and would not provide value in distinguishing between the two material types. The scoring was repeated to also include the two ratios, in addition to lead and zinc concentrations.

The scoring ranges for the zinc concentrations, lead concentrations, and the two ratios are as follows. A color was also assigned to facilitate visual analysis with evaluation of the spatial distribution as shown on Figures 8-5A, 8-5B, 8-6A, and 8-6B.

Score	Zinc (mg/kg)	Lead (mg/kg)	Zn:Cu (ratio)	Pb:Cu (ratio)
1	>1,000	>1,000	>20	>6
2	>900	>900	>18	>5.5
3	>800	>800	>16	>5
4	>700	>700	>14	>4.5
5	>600	>600	>12	>4
6	>500	>500	>10	>3.5
7	>0	>0	>0	>0

Using a combination of the zinc and lead concentration scale, with the highest concentration category being greater than 1,000 mg/kg for each of the two metals, it is clear from Figure 8-5A that all Iron King Mine site tailings samples fall into the top concentration category of “1.” On this figure, sample color codes are based on this concentration scale, and are shown as a colored ring with the ring diameter increasing with the sample depth bgs. The Zn:Cu and Pb:Cu ratios are added to the scale on Figure 8-5B for comparison, and the results are similar. Note that some samples on Figure 8-5B fall into lower categories, due to elevated copper in these samples, which reduces the ratios. This comparison demonstrates the greater consistency using only lead and zinc concentrations as shown on Figure 8-5A. The development of these figures is discussed in Appendix I.

Chaparral Gulch and the floodplain samples are plotted using the same scales and display method on Figures 8-6A and 8-6B. Samples with scores greater than “1” could indicate the presence of Iron King Mine tailings, but the tailings could be mixed with other materials with lower concentrations. Note that the Iron King Mine tailings signature (especially red through yellow rings) begins to appear to the east of Third Street. Between this point and the Humboldt Smelter site boundary, the Iron King Mine signature appears in UCD and LCD materials, with concentrations varying over the entire range of concentration ranking from red (less mixing of Iron King Mine tailings with other materials) through blue (progressively more mixing of other materials). Downstream, UCD and LCD deposits continue to occasionally display the Iron King Mine signature, and frequent occurrences of this signature also appear within the reworked tailings, as discussed above. The lowest concentration/ratio category (purple color on the figures) corresponds predominantly to the natural sediments and to undisturbed Humboldt Smelter materials.

Soil within the Tailings Floodplain that have elevated lead and zinc concentrations, and elevated Pb:Cu and Zn:Cu ratios, most closely match concentrations and ratios found for Iron King Mine tailings. Therefore, it is concluded that Iron King Mine tailings were the primary source of these materials. It is recognized that there is the potential that some elevated lead and possibly zinc materials were processed at Humboldt Smelter, based on the report in the Cultural Resource and Historic Building Survey (Appendix B) that a lead furnace was constructed at the smelter and because of the elevated concentrations of lead and zinc in the former Pyrometallurgical Operations area. However, it is concluded that lead processing at the Humboldt Smelter was very limited because no lead production reports have been found.

This analysis indicates that Iron King Mine tailings have migrated downstream to the Tailings Floodplain based on the following:

- Materials with Iron King Mine tailings signatures (elevated lead and zinc concentrations, and elevated Pb:Cu and Zn:Cu ratios) were identified in the Tailings Floodplain from Third Street to the dam.
- Visual inspection of the Tailing Floodplain from Third Street to the Smelter Swale have sporadically identified tailings in this reach. Downstream in the Middle Gulch, tailings can be seen intermittently only on the south (right) side of the Gulch and in some places, tailings have overflowed the banks and lie up to about 20 feet from the southern edge of the Chaparral Gulch bank. These observations demonstrate a migration of Iron King Mine tailings from Third Street into the Tailings Floodplain.
- The aerial photograph analysis indicates that Iron King Mine tailings were likely present in the Middle Gulch below Third Street prior to 1964.

The multiple lines of evidence indicate that Iron King Mine tailings have contributed to the elevated metals content of the Chaparral Gulch sediments from Third Street to the floodplain above the dam.

8.5 Sitewide Transport Mechanisms

This section provides a description of transport mechanisms that occur on a sitewide basis, such as aerial dispersion and groundwater transport, and that contribute to sitewide impacts. These transport mechanisms impact the sitewide metals distribution (discussed in Section 7.1), metals concentrations on residential parcels (Section 7.3), and metals concentrations in groundwater (Section 7.6).

8.5.1 Aerial Dispersion

Soil in the vicinity of the former Iron King Mine and Humboldt Smelter properties has been impacted by the deposition of windblown tailings and other wastes, as well as historical emissions and deposition of metal-rich particulates from the smelter stack during smelter operations.

Within the past 20 years, ADEQ has issued multiple air quality permit violations for the former Iron King Mine and Humboldt Smelter properties (three to the Ironite Products Company operations located on the former Iron King Mine property; one to Kuhles, owner and operator of the former Glory Hole; and one to Greenfields, the owner of the former Humboldt Smelter property). These violations are discussed in Section 3.2 and listed in Table 3-1. The different potential sources for contaminant transport by aerial dispersion, both current and during historical operations of the mine and smelter, are discussed below.

8.5.1.1 Aerial Dispersion from Former Iron King Mine Property Operational Sources

Various ore processing equipment was operated at the former Iron King property throughout the years the mine was in operation. It is likely that significant quantities of airborne dust were generated while the mine was operating, through the following operational mechanisms:

- Generation of dust during transfer of ores from the mineshaft to the mill by conveyor belt.
- Generation of dust during transportation and dumping of waste rock.
- Generation of dust during ore crushing operations and subsequent transport to ball mills and classifiers. Because the crushing step would have been performed on dry ores, significant quantities of airborne dust were likely generated during this operation.
- Generation of dust during transport of filtered lead and zinc concentrates by truck to the onsite railroad siding for shipment to smelters located in Texas. During this transportation step, lead and zinc may have been dispersed into the air and subsequently transported by aerial dispersion and deposition.

- Generation of dust through the use of heavy equipment in source areas.
- Generation of dusts from tailings impoundments after they have dried. During active placement of tailings, dust is not an issue because the tailings are deposited as a slurry; however, tailings impoundments could have dried out during the operational period if individual impoundments were unused while other impoundments are in operation.

Other ore processing steps involved wetting the ores, meaning that they were not likely a significant source of airborne dust. Given the chemical concentrations of the tailings and waste rock, dust or suspended waste materials would be expected to contain elevated arsenic and lead.

8.5.1.2 Aerial Dispersion from Former Humboldt Smelter Property Operational Sources

The following paragraphs describe aerial distribution of contaminants from ore and dross handling, and smelter stack emissions.

Ore and Dross Handling

Similar to operations at the former Iron King Mine property, various ore processing equipment was operated at the former Humboldt Smelter property throughout the years it was in operation. Ores destined for the smelter were transported via the Smelter Spur. During operation of the Val Verde Smelter at the former Humboldt Smelter property, a crusher battery was used to reduce the ore to a fine grit prior to smelting. Several types of crushers (including jaw and disc crushers) and two ball mills were also operated at the former Humboldt Smelter property, which had the capacity to crush up to 400 TPD of ore. Similar to the Iron King Mine operations, significant quantities of airborne dust were likely generated during the transportation and crushing steps, as these steps were typically performed on dry ores.

Additionally, handling of zinc and aluminum dross at the Site during the late 1950s and early 1960s may have caused zinc, aluminum, and lead to be transported via aerial dispersion. The zinc and aluminum dross was transported to the Site and spread out in the former Pyrometallurgical Operations area. Processing of the aluminum dross, in particular, involved feeding the dross into a separator and jig, grinding the dross in a ball mill, and separating the aluminum particles with a classifier. The steps used to process zinc dross are not as well documented, but they did involve transporting the zinc dross in hopper bins and processing it in brick-lined evaporating vats.

Stack Emissions

High-temperature emissions from the smelter stack are a transport mechanism for metals (notably copper and lead). Copper and other trace metal dust would have been emitted from the smelter stack and subsequently transported by aerial dispersion during routine operation of the smelter. For the constituents not volatilized but entrained as dust in the stack emissions, concentrations in the stack emissions would be roughly proportional to their concentrations in the smelter feed. Additionally, metals may have been volatilized during the smelting process, and subsequently transported via aerial dispersion. Volatilized metals would be proportionally more concentrated in the stack emissions as compared to the relative concentrations in the smelter feed. For the COIs at the Humboldt Smelter, lead is the primary metal that is readily volatilized.

As described in Section 2.1.3.2, the smelting process involved feeding copper ore and concentrates directly into a blast furnace to produce a copper matte (a copper-rich, high-sulfide intermediate smelting product) directly, or alternatively to a roaster for partial sulfur oxidation, followed by a reverberatory furnace to produce a copper matte. The copper matte from the reverberatory or blast furnace would have subsequently been conveyed to a convertor to convert the sulfide rich matte to metallic copper.

Both the initial matte production (in a reverberatory or blast furnace) and converting steps in the process involve heating the furnace charges to temperatures in excess of 1,100 degrees Celsius, which can result in metals being volatilized during either step. For example, up to 60 percent by mass of lead entering a blast or reverberatory furnace would generally be volatilized into the atmosphere, while up to 30 percent by mass of the lead entering the convertor can be volatilized into the atmosphere (the remainder of the lead is contained within either the matte or the slag from either process). Other impurities, such as zinc, are volatilized at a significantly smaller percentage (that is, only up to approximately 10 percent by mass of zinc is volatilized during the reverberatory process, and only up to 15 percent of the zinc by mass is volatilized during the converting process [Biswas and Davenport, 1980]).

Specific details on the concentrations of lead in the reverberatory furnace or converters are not available, although as stated in Section 2.3.3.1, ores processed during operation of the Agua Fria Ore Mill, Val Verde Copper Company, and Arizona Smelting Company at the former Humboldt Smelter property contained measurable concentrations of lead. Additionally, as described in Section 2, the smelter included a lead furnace during its early operation, which indicates that lead content of the smelter feed was elevated for a portion of the operational period.

With prevailing wind directions to the north and northwest during the majority of the year, and to the southeast during winter months, dust and volatilized metals may have been transported preferentially in either of these directions and subsequently deposited onto the surface soil. This transport mechanism may account for some of the exceedances of lead above screening levels observed in surface soil samples in residential properties to the north of the former Humboldt Smelter property, and within the Smelter Plateau.

8.5.1.3 Current Sources

Windblown tailings and other wastes from tailings piles, dross, and contaminated surface soil remaining at both properties may continue to be transported during high wind events. A lack of vegetative cover at and near the source areas is a factor that increases the likelihood that contaminants at the surface in these areas can be transported by aerial dispersion. As discussed in the previous subsection, wind directions are variable at the Site, but for most of the year, the prevailing wind is from the south and southeast. During the winter months, the prevailing wind direction is from the northwest.

Ambient air sampled at the former Iron King Mine property had higher concentrations of arsenic than other air sample locations, indicating the tailings are a potential source of arsenic migration. Ambient air data indicate that Humboldt Smelter source areas could be a potential source of aluminum and lead migration via aerial dispersion. However, as presented in Sections 9.6.5 and 9.7.1, no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas. Concentrations of arsenic in ambient air sampled at Humboldt Proper and the former Pyrometallurgical Operations area were similar to background concentrations. Similarly, aluminum and lead were not detected or were only detected at low levels in ambient air in Humboldt Proper.

These data do not quantify historical aerial dispersion of contaminants during mining and smelting operations, which would be expected to be significantly greater as a result of the earthmoving, excavation, and processing, activities discussed in the previous subsections.

8.5.1.4 Smelter Aerial Dispersion Contaminant Summary

As described above, contaminant transport by aerial dispersion occurred via stack emissions during smelter operations or by dust entrainment during high wind events both during operation and after smelter closure. Stack emissions included volatile metals that were preferentially released by the smelter and dust containing contaminants in similar proportion to their concentration in the smelter feed. A brief summary of the distribution of lead and copper in the former Pyrometallurgical Operations area and the residential area to the north of the smelter is presented here. Lead and copper were selected for discussion because lead is the most volatile metal contained in the smelter feed and copper likely had the highest concentrations of the non-volatile metals in the smelter feed other than iron.

Volatilization of lead from the smelting processes at the former Pyrometallurgical Operations area, and subsequent transport by aerial dispersion and deposition, may account for a portion of the lead contamination within the former Pyrometallurgical Operations area (Figure 7-2). Placement of process wastes or material spills during operations may also account for the lead distribution observed today.

The distribution of lead in surface soils in the residential areas north of the Humboldt Smelter generally indicates elevated lead concentrations closer to the smelter; however, some residential properties adjacent to the smelter have concentrations near or below background (Figure 7-34). This patchwork distribution may be due to a variety of reasons including variations in aerial dispersion patterns, importation of clean soils, and other anthropogenic activities discussed in Section 8.5.3. There are also locations with greatly elevated lead concentrations in areas north of the smelter. These include areas adjacent to the former railroad, hot spots on residential properties that were previously described in Section 7.3, and the area to the northeast of the smelter. This area to the northeast of the smelter likely received runoff from the smelter property due to surface drainage from the smelter that flows to the northeast. This area would have received aerial deposition as well.

Dust emissions from the smelter stack would have released copper as well as other metals in the smelter feed. During operation, stack emissions were likely a significant source of metal emissions because the source of the dusts was high-grade copper ores and concentrates. Additionally, the Humboldt Smelter stack would have emitted particles from an elevated position (the height of the stack), while copper-containing tailings at the Humboldt Smelter were stored in topographic low areas. Once the smelter stopped operations, the only dust sources would have been the tailings and smelter wastes remaining onsite.

The distribution of copper in the former Pyrometallurgical Operations area is likely caused by a combination of stack emissions, smelter waste product disposal, and spilled feed material (Figure 7-3). The distribution of copper concentrations in the residential properties to the north of the smelter show a general distribution of elevated concentrations directly to the north; however, as with lead, the pattern does not show a consistently decreasing concentration with distance from the smelter. There are areas adjacent to the smelter property that have copper concentrations at or below background. Also as with lead, this patchwork distribution may be due to a variety of reasons including variations in aerial dispersion patterns, importation of clean soils, and other anthropogenic activities discussed in Section 8.5.3. A portion of the heterogeneity of the copper distribution is due to the presence of other sources. For example, the area adjacent to the former railroad has elevated copper as would be expected.

8.5.2 Groundwater Transport

As discussed in Section 7.6.1, there is a clear pattern of elevated sulfate in groundwater of the Hickey Formation extending from the MTP area to downgradient areas surrounding Chaparral Gulch. Sulfate is a product of oxidation of sulfide minerals in the tailings and other mine-related materials. Although acidic pH and trace metals are also products of sulfide oxidation, they are subject to neutralization and attenuation and do not travel in groundwater as conservatively as sulfate, as discussed in Sections 8.2.2 and 8.2.3. At the Humboldt Smelter site, data indicate a smaller but distinct zone of elevated sulfate, TDS, and nitrate in the shallow groundwater of the Hickey Formation (Section 7.6.2).

The data and mechanisms cited above provide evidence that leaching from source materials at both the former Iron King Mine and Humboldt Smelter properties has resulted in limited impacts to the quality of the local groundwater. Attenuation, dispersion, and chemical reactions occur along the groundwater flow pathways, reducing the concentrations of trace element COIs and therefore limiting their impact in downgradient areas. This section discusses transport from a physical and chemical standpoint from the primary source areas (the MTP, the Smelter Tailings Swale, and the Tailings Floodplain).

8.5.2.1 Physical Transport

As described in detail in Section 5.5, groundwater occurs closest to the surface in the saturated alluvium in Chaparral Gulch near the dam. The most shallow sitewide hydrostratigraphic unit that extends through the region is the Hickey Formation, in which most of the EPA wells are screened. Below this is the Precambrian bedrock (four EPA wells characterize this zone). The distribution of these wells with piezometric surface contours is provided on Figure 5-11, and with recent COI concentrations on Figure 7-48. As described in Section 7, the primary impacts of site activity are found in the shallow groundwater of the alluvium/tailings and Hickey Formation. Although arsenic is commonly found above screening levels in the Precambrian bedrock groundwater, the chemical signature of this water differs from that of shallow groundwater and leads to the conclusion that the arsenic concentrations in this deeper zone are a reflection of natural conditions rather than mine or smelter activity. As described in Section 7, the Precambrian bedrock groundwater contains low levels of sulfate, the primary tracer of mine impacts, and the groundwater has a lower TDS and greater sodium presence than impacted water from the Hickey Formation (see Figure 7-48). The emphasis on transport is therefore limited to the shallow groundwater units.

Once leached into shallow groundwater beneath the source areas, the transport of COIs is expected to follow the generally west-to-east flow path of local shallow groundwater to the Agua Fria River, roughly following the local surface drainage patterns. Along the flow path, dissolved constituents such as sulfate and trace metals are expected to naturally disperse laterally and vertically to produce a wider distribution at a lower concentration than found directly beneath the source areas. The amount of dispersion will vary with the physical properties of the aquifer matrix. In the case of alluvium and tailings, dispersion will be minimal as these are not continuous saturated units. Groundwater emerging from these units will either discharge to the surface or infiltrate to the underlying Hickey Formation aquifer.

The Hickey Formation contains many fine-grained zones (Section 5.5), and dispersion is expected to occur in the coarser-grained zones, resulting in a network of preferred flow paths that widen downgradient. Because sulfate is more chemically conservative than trace metals or pH, as well as relatively unique to mine workings and tailings sources, it provides the most effective assessment of the physical transport patterns from source areas. The distribution of sulfate concentrations above 100 mg/L in groundwater downgradient of the MTP on Figure 7-54 provides a rough trace of groundwater dispersion. TDS and nitrate also tend to also move conservatively through groundwater (as long as conditions remain oxidizing enough to support nitrate), but there may be other natural or non-mining anthropogenic sources that reduce their reliability as tracers. Trace metals and pH may undergo a variety of chemical reactions along the flow path (these are discussed in the next section).

The Hickey Formation groundwater is clearly impacted by elevated sulfate immediately east (downgradient) of the MTP and the former Iron King Mine property boundary (MW-07S). The elevated sulfate is also found in wells surrounding Chaparral Gulch downstream of the mine property, ranging between 260 and 1,300 mg/L in MW-10S and GW-999945 in the upstream reach to 220 and 270 mg/L in GW-999958 and GW-999903 downstream toward the former Humboldt Smelter property boundary. This impact drops off immediately to the north, where wells GW-999963 and GW-999964 have sulfate between 50 and 60 mg/L, which is within the range of the unaffected wells in Dewey-Humboldt and in wells further north. This pattern suggests a mine-impacted zone that is relatively narrow, closely approximating the surface drainage toward the smelter property and Lower Chaparral Gulch.

8.5.2.2 Chemical Reactions during Transport

As discussed in detail in Section 8.1, the principal source of trace metals at the Site is the oxidation of sulfide minerals that contain the trace metals (for example, lead, zinc, cadmium, copper, and arsenic). In this reaction, sulfide is oxidized to sulfate and released into solution along with iron, trace metals, and acid, creating ARD. While all the tailings samples from the MTP have ABA measurements indicating significant acid-generating potential (Section 8.2.2), there are no groundwater wells that display pH consistently below 6, demonstrating that the subsurface contains abundant enough natural material (such as $CaCO_3$) that it has neutralized these acids up to the present time.

Wells with sulfate concentrations above the 250-mg/L screening level, reflecting these ARD reactions, have a median pH of about 6.9, compared to wells with low sulfate (less than 100 mg/L), which have a median pH of about 7.2. There is a great deal of overlap in measured pH between these groups, demonstrating the overall effectiveness of the NP of both soil and aquifer matrix materials. Although the amount of ABA data on non-mining or non-mineralized materials is relatively small, these materials have consistently positive NNP values. Given the much greater volume of this material compared to the acid-generating material, as indicated by cross sections presented in Section 5.5, it is not likely that the depletion of natural NNP will be complete in the near future. The only observations of pH below 6 that have been observed in any site well were two samples from Precambrian bedrock wells (MW-06D and MW-07D) in October 2012. These pH values have not been reproduced and as discussed in Section 7, the bedrock chemistry appears to reflect natural, mineralized conditions and not the result of activity at the mine site.

The two trace metals that have exceeded screening levels most frequently in soils are lead and arsenic. Lead was one of the principal ore metals (along with zinc) at the former Iron King Mine property, and occurs in the mineralized zone as the sulfide mineral galena (lead sulfide). Although lead is released to solution during the ARD reactions described previously, this metal is not mobile outside of a highly acidic environment. At the pH range observed in site groundwater, the following is noted: (a) lead is likely to form insoluble oxides, and (b) whatever ionic lead is left over is strongly adsorbed to soil minerals such as iron oxides and clays. These chemical constraints normally maintain dissolved lead at concentrations well below the screening level, and commonly below typical analytical detection limits.

Suspended particulates (colloids) present in groundwater samples, and especially common in small-diameter environmental monitoring wells, would be expected to contain some fraction of lead oxide. Although many colloids are small enough to pass through the standard 0.45-micrometer filter used to collect “dissolved” metals samples, it would be expected to find greater lead concentrations in total vs. dissolved samples if colloids were playing a role in lead measurement. Figures 7-51 and 7-52 show that this is what is observed, with far more frequent and greater concentrations of total lead in the groundwater samples. Additionally, there were no exceedances of the screening level outside of the deep mine workings well (GW-999954) and a single sample from well MW-08D (the other sample from this well was nondetect). Given the near-absence of screening level exceedances, the known geochemical constraints on lead mobility, and the abundance of iron oxides in both the natural and mine-related materials, lead is not expected to be mobile or a threat to downgradient receptors at the Site.

Arsenic is a common impurity in sulfide minerals, especially in pyrite (iron sulfide). Pyrite is the most common sulfide mineral in any massive sulfide deposit such as those at the former Iron King Mine property. Arsenic concentrations in the MTP are elevated and average near 4,000 mg/kg. Pyrite was also the most common sulfide mineral in the sulfide ores that were shipped to and processed at the former Humboldt Smelter property during its earlier operational period. However, arsenic concentrations in the Smelter Tailings Swale were considerable lower and averaged approximately 120 mg/kg. Arsenic, if present in the tailings, can be released during ARD generation. Arsenic also adsorbs to iron oxide minerals very effectively, especially in environments in which the oxidized form of arsenic or arsenate is predominant. Where iron oxide adsorbents are abundant, they act to maintain low arsenic concentrations by adsorption to their surfaces. Unlike lead, arsenic is (a) more naturally abundant, and (b) in the form of a negatively charged ion in the site groundwater pH range. These qualities cause arsenic to be more mobile than lead in this environment. As a result, arsenic is found above screening levels in some of the ARD-impacted wells in and between the two properties (for example, MW-03S, MW-07S, GW-999908, and CHF-MW-01; Figures 7-49 and 7-50).

Concentrations of arsenic in groundwater tend to be highly variable, partly due to the colloid effect described above for lead, but also due to the large range of arsenic content of source materials. In zones of the aquifer where arsenic sources are particularly rich, the local adsorption sites on iron oxides may be eventually saturated, resulting in a lack of attenuation in these areas. As the arsenic stays in solution and is transported downgradient, it would be expected to disperse and find additional iron oxides for attenuation. With this process continuing downgradient, arsenic concentrations will vary as a function of the ratio of arsenic to adsorption site availability.

Also unlike lead, arsenic is common in natural rocks and soils of the area, outside of the mineralized zone of Iron King Mine and the waste materials of the former Humboldt Smelter property. Exceedance of the arsenic screening level is common in non-EPA wells of the area, including many that are clearly outside the pathway of groundwater flow from either property (Figures 7-49 and 7-50).

Sulfate remains the most effective tracer of potential mine/smelter impact to groundwater – the concentration of sulfides in these source areas is greater than that of natural arsenic sources, so regional wells have much lower sulfate content even while arsenic is above screening levels. There is no discernable evidence that arsenic impacts from the Iron King Mine or Humboldt Smelter extend beyond the sulfate-impacted areas described above. The geochemically more conservative nature of sulfate supports this conclusion.

8.5.3 Sitewide Anthropogenic Factors

Development of the area near the former Iron King Mine property and former Humboldt Smelter property during the more than 100 years since operations began has resulted in the redistribution of contamination caused by earlier mechanisms of surface water transport, aerial deposition, rail transport, or dumping. In addition, there are numerous non-site-related sources that have impacted concentrations. The result of site-related and non-site-related sources of metals, in addition to the redistribution of contamination during development, has resulted in a complex patchwork distribution of metals in residential areas.

Anthropogenic factors have included the following:

- Mine waste (such as tailings and waste rock) was historically used as fill and road base in adjacent areas, including some residential areas. Waste from the former Humboldt Smelter property may have been used in a similar fashion.
- Contaminated soil has been redistributed during redevelopment of the area. Grading, cutting, and filling material within residential or commercial properties have modified the distributions of arsenic and lead. Residential properties that were formerly commercial properties may contain elevated levels of contamination due to prior commercial activities.
- Other non-site-related sources of arsenic and lead have influenced concentrations at select properties, as discussed in Section 7.3. Naturally occurring arsenic (and other metals) is associated with silicic volcanic materials such as rhyolite, which are widely present within the region. Fill has been imported from quarries with naturally elevated concentrations of arsenic, and cut-and-fill activities have occurred in areas of naturally elevated concentrations of arsenic east of the Agua Fria River. Non-site-related anthropogenic sources of lead include use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires.
- The historic Prescott and Eastern Railroad serviced the mining and smelter operations at the former Iron King Mine and Humboldt Smelter properties. Historical spills and releases likely occurred along the rail line, and the materials could have been subsequently redistributed during redevelopment. A 1.5-mile rail spur, known as the Smelter Spur, connected Humboldt Smelter to the Prescott and Eastern Railroad. This spur goes through the current downtown area of Humboldt Proper and entered the Humboldt Smelter from the northwest (the location of the rail line is illustrated on

Figure 2-2). Elevated arsenic and lead concentrations occurred in a linear area in Humboldt Proper along the Smelter Spur. The distribution of elevated arsenic concentrations in this area is consistent with historical spills of feed material for the Humboldt Smelter along the rail right-of-way, and the subsequent redistribution of these materials during redevelopment of this area.

The sitewide metals distribution is discussed in Section 7.1. Metals concentrations on residential parcels is discussed in Section 7.3. Sitewide transport mechanisms, including aerial dispersion, are discussed in Section 8.5.1.

8.6 Conceptual Site Model

Contaminant sources at the former Iron King Mine and Humboldt Smelter properties are associated primarily with stockpiled mine and smelter wastes created during a long history of operations beginning in the late 1800s. Site contaminants, primarily metals such as lead and arsenic, have impacted neighboring residential and municipal properties in addition to other areas surrounding the former mine and smelter properties.

Contamination migrated from the primary source areas associated with the former Iron King Mine and Humboldt Smelter properties via a number of release and transport pathways during and after active operations. These include:

- Historical operational discharges
- Impoundment failures
- Placement of mine and smelter waste in drainages or on nearby properties
- Erosion during storm events
- Spills during transport along rail routes
- Historical smelter stack emissions
- Windblown particulates, including tailings, dross, and contaminated soil
- Use of mine waste material as fill material or road base
- Redistribution of contamination during development

8.6.1 Source Areas and Historical Operational Releases

Mining and smelting operations at the former Iron King Mine and Humboldt Smelter properties resulted in the accumulation of source materials in distinct areas on each property, and off-property releases during operations.

Figure 8-7 provides an oblique aerial view showing the key features of the Site, including the former Iron King Mine and Humboldt Smelter properties, primary source areas at the two properties, the relative location of the Town of Dewey-Humboldt, and the regional surface water features. The boundary of the APSI is also shown.

Substantial source areas on the former Iron King Mine property include the following:

- **MTP.** Mining of the massive sulfide deposit at Iron King Mine produced tailings as the mining progressed over several decades. The tailings were placed in various impoundments running eastward and southward from the former Mineworks area in historical drainages to Chaparral Gulch. The massive pile that currently exists is referred to as the “Main Tailings Pile” or “MTP.” These tailings, though not of ore grade, contain large concentrations of sulfide minerals, predominantly iron sulfide, that also contain trace metals such as arsenic, cadmium, lead, and zinc. Approximately 3.5 million yd^3 of milled waste (tailings) were deposited.

- **Former Small Tailings Pile.** The Small Tailings Pile, located north of the MTP within a drainage tributary to Chaparral Gulch, was a source of contamination to Chaparral Gulch prior to its removal and consolidation with the MTP in 2011. The volume of the tailings removed was 21,500 yd^3.

- **Waste Rock.** Waste rock associated with former mining operations occurs in piles and as a veneer across the former Mineworks area and the former Fertilizer Plant area. Waste rock also has been deposited adjacent to Galena Gulch.

Substantial source areas on the former Humboldt Smelter property include:

- **Former Pyrometallurgical Operations Area.** This was the location of ore offloading, ore concentrating, smelting, and discharge or storage of waste materials. Dross was imported after closure and dismantling of the Humboldt Smelter plant for reprocessing to recover aluminum and zinc and is widely spread across much of the area.
- **Smelter Tailings Swale.** Tailings in the Smelter Tailings Swale were produced as a waste product from concentrating ore to feed the smelter.
- **Tailings Swale and Floodplain.** Impoundment failures and historical discharges from the former Iron King Mine and former Humboldt Smelter properties released tailings into Chaparral Gulch. These materials combined with other soil materials from Upper Chaparral Gulch to form the Tailings Floodplain.
- **Smelter Slag.** The primary smelter slag pile is located along the eastern side of the property, with a smaller satellite pile on the Smelter Plateau to the south. The slag deposits have formed a steep bluff overhanging the Agua Fria River, and slope failures have occurred in some areas.
- **Lower Chaparral Gulch and Agua Fria Tailings Piles.** Tailings deposits are located along Lower Chaparral Gulch, and the Agua Fria River just downslope of the former Chaparral Gulch Shaft, and are likely the result of predecessor mining and milling operations.

During active periods of operations at each property, release and transport of wastes out of the areas of primary operations occurred. Figure 8-8 provides a conceptual depiction of the primary contaminant transport mechanisms such as historical operational discharges; surface water transport resulting from erosion, stormwater discharges, or impoundment failures; aerial dispersion; and historical spills along rail lines.

At the former Iron King Mine property, the following historical operational releases were sources of contamination to Chaparral Gulch, Galena Gulch, the Agua Fria River, and adjacent properties:

- **MTP Blow Out.** The largest known tailings release event occurred during a slope failure of the MTP in 1964. This MTP Blow Out formed what is now the lower MTP, and tailings were transported under the current location of Highway 69 to Chaparral Gulch and the Agua Fria River.
- **Discharges of Process Water and Tailings Releases.** Routine discharge of process water may have occurred at Iron King Mine, such as overflow from tailings ponds or discharge of poor-quality process water that could not be recycled. Tailings pond outfalls and smaller tailings pond berm breeches were observed in historical aerial photographs, indicating that tailings releases may have occurred during storm events prior to the MTP 1964 Blow Out event (EPA, 2008d). In addition, it is unknown how tailings were managed during very early mining operations. Tailings may have been contained in smaller precursor tailings ponds, or potentially discharged directly to the intermittent drainages. Stormwater releases also occurred during the NAI fertilizer operations (see Section 3).
- **Placement of Mine Waste in Drainages.** Mine waste appears to have been dumped or placed along Galena Gulch, and tailings were deposited adjacent to Chaparral Gulch in the former Small Tailings Pile.

At the former Humboldt Smelter property, the following historical operational releases were sources of contamination to Chaparral Gulch, the Agua Fria River, and adjacent properties:

- **Impoundment Failures and Historical Discharges to Chaparral Gulch.** Impoundment failures and historical discharges from operations at both the former Humboldt Smelter and former Iron King Mine properties released tailings into Chaparral Gulch, forming the Tailings Floodplain. Breaches in the Smelter Tailings Swale berm were evident in the earliest historical aerial photograph from 1940. In addition, it is unclear when the Smelter Tailings Swale berm and Chaparral Gulch Dam were constructed. The Tailings Floodplain upstream of the dam may have been the primary tailings pond for Humboldt (and possibly Val Verde) Smelter during much of its operation.
- **Smelter Stack Emissions.** Metal-containing particulates and volatile metals (primarily lead) discharged from the Humboldt Smelter stack during operations would have been a potential source of metals to adjacent properties.
- **Material Placement.** There is evidence of a historical narrow-gauge rail on the eastern edge of the smelter that was used to transport pots of molten slag to the cliff over the Agua Fria River for disposal. After closure of the smelter, dross was stockpiled on the property for processing. The Agua Fria Tailings Pile is likely the result of tailings that were tremied or slurried from this predecessor mining and milling operation.

At both the former Iron King Mine and Humboldt Smelter properties, the following historical operational releases occurred:

- **Rail Operations.** The historic Prescott and Eastern Railroad serviced the Iron King Mine, Humboldt Smelter, and Val Verde Smelter. Historical spills and releases likely occurred along the rail line, and the materials could have been subsequently redistributed during redevelopment. A 1.5-mile rail spur, known as the Smelter Spur, connected Humboldt Smelter to the Prescott and Eastern Railroad. This spur goes through the current downtown area of Humboldt Proper and entered the Humboldt Smelter from the northwest.
- **Dust Emissions.** Use of heavy equipment; activities such as excavating, blasting, and milling; and loading and transport of materials would have resulted in suspension and migration of fine-grained materials, including tailings and dross.
- **Use of Mine Waste in Construction and Redistribution of Contamination during Development.** Mine waste (such as tailings and waste rock) was historically used as fill and road base in adjacent areas, including some residential areas. In addition, contaminated soil has been redistributed during redevelopment of the area.

Figure 8-9 provides a conceptual depiction of a cross section of the Site from the former Iron King Mine property along the MTP 1964 Blow Out Path to Chaparral Gulch, down the gulch through the Tailings Floodplain, and to the Chaparral Gulch Dam. The figure includes a conceptual depiction of ARD generation, leaching of metals, and groundwater flow and transport mechanisms.

8.6.2 Aerial Dispersion

Soil in the vicinity of the former Iron King Mine and former Humboldt Smelter properties has been impacted by the deposition of windblown tailings and other wastes, as well as historical emissions and deposition of metal-rich particulates from the Humboldt Smelter stack during smelter operations (Figure 8-8). Where arsenic or lead concentrations are elevated in shallow soil samples collected off-property, their concentrations are typically lower in the collocated deeper samples, which is consistent with aerial deposition of windblown dusts and smelter emissions. However, as discussed in the following section, anthropogenic factors such as grading for property development and importing fill for landscaping have significantly altered distribution of arsenic and lead in downwind areas and generated a more complex patchwork pattern to the distribution of metals in residential surface soils.

It is likely that significant quantities of airborne dust were generated while the mine and smelters were operating. At the former Iron King Mine property, sources of airborne dusts during active mining and milling operations would have included:

- Transportation of ore from the mine to the mill via conveyors
- Transportation and dumping of waste rock by truck
- Transportation and loading of products (concentrates) by trucks and rail
- Crushing of dry ores in multiple steps of crushing with intermediate screening
- General use of heavy equipment for activities such as facility and road construction
- Suspension and migration of fine-grained materials by wind from dry portions of the tailings ponds

North of the former Iron King Mine property, a series of slopes and ridges are oriented perpendicular to the primary wind direction at progressive distances from the mine. Arsenic levels north of the MTP are highest on the upslope to the first ridge, at the ridgeline, and to some extent on the backslope over the top. Levels at the next ridge are considerably lower and more variable, and by the third-to-fourth ridges and slopes, levels of arsenic have fallen to background levels. It appears that the slopes to the ridges serve as windbreaks, with the first slope ridge intercepting much of tailings migrating from the MTP.

At the former Humboldt Smelter property, significant quantities of airborne dust were likely generated during the transportation and crushing of ore, as these steps were typically performed on dry ores.

High-temperature emissions from the smelter stack were an aerial transport mechanism for metals. Emissions from the smelter stack would have consisted of metal-rich dust, and also metals that were volatilized from the smelting process. The concentration of metals in dust emissions would be roughly proportional to their concentrations in the smelter feed (and subsequently would be expected to be copper-rich). Metals volatilized during the smelting process would have consisted predominantly of lead. With prevailing wind directions to the north and northwest during the majority of the year and to the southeast during winter months, dust and volatilized metals may have been transported preferentially in either of these directions and subsequently deposited onto the surface soil.

These transport mechanisms may account for some of the exceedances of lead above screening levels observed in surface soil samples in residential properties to the north of the former Humboldt Smelter property, and within the Smelter Plateau. Despite a complex pattern to the distribution of lead in residential surface soils, levels above background and screening levels are in general more prevalent in areas near the smelter as compared with areas farther from the smelter and outside the APSI. However, there are some residential properties adjacent to the northern boundary of the former Humboldt Smelter that have lead in surface soils at or below background. It is not clear if these conditions are due to variations in aerial dispersion, importation of clean soils, or other processes. Copper, while not present in residential soils at levels that pose a health risk, shows a distinct distribution of concentrations above background in residential soils in areas around the smelter, providing additional evidence for historical impacts from smelter stack emissions.

Handling of zinc and aluminum dross at the Site during the late 1950s and early 1960s likely caused zinc and aluminum to be transported via aerial dispersion. Processing of the aluminum dross, in particular, involved feeding the dross into a separator and jig, grinding the dross in a ball mill, and separating the aluminum particles with a classifier. The steps used to process zinc dross are not as well documented, but they did involve transporting the zinc dross in hopper bins and processing it in brick-lined evaporating vats. Zinc and aluminum dust had the potential to be generated and transported by aerial dispersion in the process of handling the zinc and aluminum dross.

Windblown tailings and other wastes still found on the two properties may continue to be transported via aerial dispersion during high wind events. Ambient air monitoring data collected in 2008 and 2009 indicate wastes remaining at the former Iron King Mine and Humboldt Smelter properties are potential sources of arsenic and lead migration, respectively, during high wind events. A lack of vegetative cover in the area increases the likelihood that contaminants in surface soil at these areas can be transported by aerial dispersion. However, as presented in Sections 9.6.5 and 9.7.1, no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas.

8.6.3 Placement and other Anthropogenic Factors

Development of the area near the former Iron King Mine and Humboldt Smelter properties during the more than 100 years since operations began has resulted in the redistribution of contamination, resulting in a more complex patchwork distribution of metals in residential areas. Anthropogenic factors have included the following:

- Iron King Mine waste material (such as tailings and waste rock) was historically used as fill and road base in adjacent areas, including some residential areas, and smelter waste may have been used in a similar fashion.
- Soil has been redistributed during redevelopment and other human activities in the area over the many decades since smelter and mine operations ceased. Grading, cutting, and filling material within residential or commercial properties have modified the distributions of arsenic and lead caused by earlier mechanisms of surface water transport, aerial deposition, rail transport, or dumping.
- There have been changes in land use from historical commercial or industrial land use to residential.
- The historic Prescott and Eastern Railroad serviced the Iron King Mine, Humboldt Smelter, and Val Verde Smelter. Elevated arsenic and lead concentrations occurred in a linear area in downtown Humboldt along the Smelter Spur entering the Humboldt Smelter property. The distribution of elevated arsenic concentrations in this area is consistent with historical spills and releases of feed material for the Humboldt Smelter along the rail right-of-way and the subsequent redistribution of these materials during redevelopment of this area.
- Other non-site-related sources of arsenic and lead have influenced concentrations at select properties. Naturally occurring arsenic (and other metals) is associated with silicic volcanic materials such as rhyolite, which are widely present within the region. Fill has been imported into a small number of yards from quarries with naturally elevated concentrations of arsenic, and cut-and-fill activities have occurred in areas of naturally elevated concentrations of arsenic east of the Agua Fria River. Non-site-related sources of lead include use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires.

8.6.4 Surface Water and Sediment Transport

Mine and smelter wastes (including tailings, waste rock, and slag) were released, dumped, or placed within surface water features, or in areas that drain to surface water features. Galena Gulch transects the southwestern portion of the former Iron King Mine property adjacent to the former Mineworks area. Abandoned mine shafts and areas of waste rock are present on bedrock benches and adjoining slopes along Galena Gulch south of this area. Chaparral Gulch has been impacted by impoundment failures and historical discharges from operations at both the former Iron King Mine and Humboldt Smelter properties. On the former Humboldt Smelter property, the Chaparral Gulch Dam was used to impound tailings and alluvium; the Tailings Floodplain formed upstream of the dam within the gulch channel. The Agua Fria Tailings Pile is located along the Agua Fria River near the confluence with Chaparral Gulch.

Surface water flows from the former Iron King Mine and Humboldt Smelter properties have carried mine wastes, contaminated soil, and ARD downstream via the Chaparral and Galena Gulch drainages to the Agua Fria River (Figure 8-8). Surface water and sediment data confirm that the following surface water transport mechanisms have occurred at these properties:

1. Direct release and redistribution of mine waste and smelter waste during historical operations
2. Erosion and deposition of mine waste and smelter waste or contaminated soils
3. Discharge of metals through ARD mechanisms
4. Precipitation and dissolution reactions, providing a flux of contaminants between surface water and sediment
5. Evapoconcentration of metals due to repeated wetting and evaporation on tailings

During high intensity rainfall events, precipitation runs off unvegetated mine waste piles and areas of dispersed mine waste at Iron King Mine and has resulted in erosion and transport of contaminants with subsequent deposition of contaminants downstream. Mine waste or contaminated soil is also eroded from existing areas of deposition, such as the Iron King Mine tailings in Chaparral Gulch, which can subsequently be transported downstream.

Similarly, precipitation runs off unvegetated waste piles and areas of dispersed waste and contaminated soils at the former Humboldt Smelter property that has resulted in erosion, transport, and deposition of contaminants. Tailings and smelter waste or contaminated soil are also eroded from existing areas of deposition, such as the Smelter Tailings Swale and the Tailings Floodplain, which can be subsequently transported to Lower Chaparral Gulch and into the Agua Fria River.

The highest concentrations of COIs detected in sediment and surface water were within and at the base of the MTP, in Chaparral Gulch downstream of the former Iron King Mine property, and in the Tailings Floodplain upstream of the Chaparral Gulch Dam. Site-related contamination in the Agua Fria River is limited to locations near the former Humboldt Smelter property source areas and at and immediately downstream of the confluence with Chaparral Gulch.

Although background concentrations in surface water and sediment have not been formally determined, upstream surface water and sediment samples, along with the sitewide soil background dataset, indicate there are also naturally occurring sources of COIs at concentrations exceeding screening levels. These metals include arsenic and copper in sediment.

Concentrations of some metals in surface water and sediment in the Agua Fria River exceed the screening levels in a large number of samples and have comparable concentrations both upstream and downstream of the Iron King Mine and Humboldt Smelter source areas. As an example, 95 percent of samples exceed screening levels in surface water for barium, including all samples collected from upstream reaches of the Agua Fria River. Also, arsenic and copper exceed screening levels in a large percentage of upstream sediment samples. Most of the flow in the Agua Fria River upstream of the Town of Dewey-Humboldt consists of effluent from the Prescott Valley Wastewater Treatment Plant (ADEQ, 2009). In addition, there are upstream agricultural uses (see Figure 5-16A), and local geology results in elevated mineralization in soils and alluvial materials eroded from these areas.

8.6.5 Chaparral Gulch Alluvium Deposits and Tailings Floodplain Formation

Historical impoundment failures at the former Iron King Mine property and the former Humboldt Smelter property have released tailings into Chaparral Gulch, where they have been reworked and redeposited by stormwater flow, and mixed with native alluvial materials.

The alluvium deposits in Chaparral Gulch upstream of the Chaparral Gulch Dam were subdivided into six alluvial units based on site-specific investigations (from shallow to deep). The UCD, HSCD, and LCD consist of mixed tailings and fluvium based on stratigraphic position, physical characteristics, and chemical characteristics. Together with tailings, these channel deposits formed during or after operations at the former Iron King Mine and Humboldt Smelter properties. The volume of contaminated UCD, tailings, HSCD, and LCD deposits between Third Street and the dam is estimated as 280,000 yd^3. The Brown Clay and PFG are interpreted to be native Quaternary alluvial deposits that predate operations at the former Iron King Mine and Humboldt Smelter properties.

The Tailings Floodplain formed over many years as a result of historical operational releases from the former Iron King Mine and Humboldt Smelter properties and deposition of tailings in Chaparral Gulch above the Chaparral Gulch Dam (Figure 8-8). On the former Humboldt Smelter property, tailings were placed in the Smelter Tailings Swale or discharged directly to the Tailings Floodplain during the active years of the smelter operations (1899 to 1937). Breaches of the Smelter Tailings Swale containment berm occurred. Storm events caused progressive migration of tailings materials downslope toward Chaparral Gulch.

At the former Iron King Mine property, tailings impoundments were constructed along a natural drainage that leads to Chaparral Gulch. Minor breaches of these impoundments, along with drainage to Upper Chaparral Gulch, contributed mine waste to Chaparral Gulch at the drainage confluence east of Third Street throughout the 1940s and 1950s. A mine employee estimated that the MTP Blow Out contributed an estimated volume of up to 5,000 tons of tailings into Chaparral Gulch (Kentro, 1964), although the basis for this estimate was not substantive. Tailings in Chaparral Gulch derived from operations at the former Iron King Mine property were transported downstream toward the dam along with the natural sediments during various storm events.

The chemical properties of mine and smelter tailings are distinctly different. Key metals (lead, copper, and zinc) and their ratios (Pb:Cu and Zn:Cu) were used to evaluate the nature, extent, fate, and transport of contamination from the former Iron King Mine and Humboldt Smelter properties. The Iron King Mine tailings are distinguished by the highest average concentrations of lead and zinc, whereas copper tends to be the dominant metal in tailings from the former Humboldt Smelter property. Floodplain samples show that tailings from both sources are present, and groundwater within and beneath these materials has also been impacted (Figure 8-9). The data demonstrate that Iron King Mine tailings have contributed to the elevated metals content of the Chaparral Gulch sediments from Third Street to the Tailings Floodplain immediately above the dam. Between Third Street and the former Humboldt Smelter property boundary, the Iron King Mine signature occurs in UCD and LCD materials. Downstream, UCD and LCD deposits occasionally display the Iron King Mine signature, and frequent occurrences of this signature also appear within the reworked tailings. The data indicate that the Iron King Mine tailings and upstream alluvial material were constricted to the more southerly edge of the Tailings Floodplain, around the smelter tailings migrating south from the Smelter Tailings Swale.

8.6.6 Acid Rock Drainage and Groundwater Transport

8.6.6.1 Acid Rock Drainage and Site-Related Groundwater Impacts

As sulfide minerals in the stockpiled tailings are exposed to air and oxygen-rich rainwater and surface runoff, they are oxidized and partially dissolved, releasing trace metals along with sulfate and acidity to the water. Evidence of ARD impacts from stockpiled tailings to surface water and shallow groundwater has been observed in the vicinity of the former Iron King Mine and Humboldt Smelter properties, as discussed in this section. The inferred groundwater and surface water pathways are shown on Figure 8-8 and in cross-section view on Figure 8-9. ARD impacts from deeper saturated materials and mine workings are not significant because the workings are located far below the shallow water table and remain submerged.

The primary chemical parameters that influence ARD generation and transport in site materials are the AP and NP (and the resultant NNP). However, there are several physical properties of the materials including the moisture content, particle size distribution, hydraulic conductivity, and water infiltration rates that also affect the rate and extent of ARD generation and subsequent transport of ARD products. These physical conditions have a significant impact on the rate of sulfide oxidation, ARD production, and contaminant transport in the MTP.

Moisture content influences oxygen transport into the tailings with generally lower oxygen transport at higher moisture content. Lower oxygen transport results in decreased oxidation of the tailings. The particle size distribution influences the rate of chemical reaction. Smaller particles have higher surface area available for reaction, but finer particle sizes also typically have lower hydraulic conductivity, and hence, lower rates of vertical water transport downward through the tailings. With less water transported through the tailings at lower hydraulic conductivities, water infiltration through the tailings occurs episodically, triggered by significant rain events. Wetting and drying cycles on the surface of the MTP result in the formation of efflorescent salts.

A portion of the precipitation that falls on the MTP evaporates, and the remainder infiltrates, effectively pushing entrained water vertically downward through the unsaturated tailings. The degree of saturation of the tailings is likely variable over time, based on the precipitation pattern. Dissolved salts that have accumulated in the entrained water, along with freshly leached salts in the infiltrating water, are transported downward through the pile and eventually through the native soil to the water table. This is likely a slow transport process given the limited rainfall, the episodic nature of significant rainfall events, and the low permeability of the tailings.

The limited oxidation of the tailings with depth in the MTP (observed as less than 2 feet deep in the 2014 SERAS borings) indicates that the rate of oxygen transport into the pile is low compared to the oxygen demand required to oxidize the sulfides in the tailings. This indicates that oxidation of the tailings and generation of ARD is proceeding, but the oxidation front is moving slowly through the tailings.

As ARD-impacted waters flow along the surface or infiltrate to the water table, the sulfate tends to move conservatively and remain in solution, providing an effective tracer of the tailings sources. The associated acidity, as represented by pH, is being effectively buffered by remaining NP in the tailings and waste rock, and by minerals in the surrounding soils (for example, $CaCO_3$). The trace metals are mostly adsorbed to mineral surfaces, a process that removes them from solution, except where the minerals are carried as suspended particulates in surface or groundwater. Minerals present prior to mine operations along with precipitated iron oxides from tailings sources both serve as trace metal adsorbents in this process. In localized areas where there are insufficient adsorbent surfaces exposed to the water, trace metals concentrations exceed the screening levels.

Sulfate concentrations in surface water above 1,000 mg/L were detected in samples collected from the retention ponds on top of, and at the base of, the Iron King Mine MTP and from the Tailings Floodplain and Lower Chaparral Gulch. The concentration of sulfate was low (below 100 mg/L) in all reaches of the Agua Fria River, indicating that the transport of ARD has not significantly impacted the river.

The primary impacts of ARD and site-related sources are observed in shallow groundwater at the bottom of and underlying the MTP, shallow groundwater in the alluvium of the Tailings Floodplain, and localized areas in the Hickey Formation. The Hickey Formation is the shallowest groundwater unit that extends across the Site. Below the Hickey Formation is the Precambrian bedrock. No site-related impacts are evident in the Precambrian bedrock.

The Hickey Formation groundwater is clearly impacted by elevated sulfate immediately east (downgradient) of the MTP and the former Iron King Mine property boundary. Elevated sulfate is also detected in wells in the vicinity of Chaparral Gulch downstream of the former Iron King Mine property. To the north, unimpacted wells within Dewey-Humboldt suggest a mine-impacted zone that is relatively narrow, closely following the surface drainage downstream and downgradient along the Chaparral Gulch toward the former Humboldt Smelter property.

While all the tailings samples from the MTP have ABA measurements indicating significant acid-generating potential, there are no groundwater wells that display pH consistently below 6. This indicates that residual neutralizing capacity in waste materials and local soils and groundwater matrix minerals are buffering the ARD acidity.

Arsenic, lead, and TDS locally exceed screening levels in the shallow Hickey Formation and Chaparral Gulch alluvium aquifers and in groundwater at the bottom of and underlying the MTP. ARD impacts from metals are more localized than sulfate. Although lead is released to solution during the ARD reactions described previously, this metal is not mobile outside of a highly acidic environment.

8.6.6.2 Dross Operations and Groundwater Impacts at the Former Humboldt Smelter Property

Groundwater near the former Humboldt Smelter property is locally impacted by chloride, nitrate, and TDS. These exceedances may be related to releases of wastewater associated with dross processing, leaching of exposed dross, or a combination of these processes. The TDS, chloride, and nitrate impacts, along with some elevated sulfate, associated with the former Humboldt Smelter property may extend off-property to the north based on samples from nearby domestic wells.

8.6.6.3 Regional Groundwater Quality Unrelated to Site Operations

The townsite contains numerous public and residential supply wells that show local groundwater contains low sulfate but locally high TDS, arsenic, and/or nitrate. Comparison of available chemical data suggests that these impacts are not related to Site operations. Deeper groundwater in the underlying Precambrian bedrock has a markedly different chemical signature indicating little hydraulic communication with the overlying Hickey Formation. Arsenic is common in natural rocks and soils of the area, outside of the mineralized zone of Iron King Mine and the waste materials of Humboldt Smelter. Elevated TDS and nitrate are common properties of septic system leachate and past agricultural activities. Most of the wells with these regional impacts are outside the groundwater flow path from the former Iron King Mine or Humboldt Smelter properties

SECTION 9

Baseline Human Health Risk Assessment

This section provides the results of the baseline HHRA performed as part of the RI for the Iron King Mine – Humboldt Smelter Superfund Site. The risk assessment identifies and characterizes the toxicity of the chemicals of potential concern (COPCs), the potential exposure pathways, the potential human receptors, and the likelihood of adverse health effects under current and reasonably anticipated future land and water use conditions.

EPA uses risk assessments to characterize the nature and magnitude of health risks to humans (residents, workers, and recreational visitors) and ecological receptors (birds, fish, and wildlife) from chemical contaminants and other stressors that may be present in the environment. Chemical concentrations are measured in various media (soil, ambient air, sediment, and surface water) to characterize the nature and extent of chemical contamination in the environment, and evaluate how the contaminants may behave in the environment. The risk assessment evaluates the frequency and magnitude of human and ecological exposures that may occur because of contact with the contaminated media, both now and in the future. This evaluation of exposure is then combined with information on the inherent toxicity of the chemical (that is, the expected response to a given level of exposure) to predict the probability, nature, and magnitude of the adverse health effects that may occur. EPA uses the information from the risk assessment to determine whether site cancer or noncancer risks are great enough to potentially cause health problems for people at or near the Site.

As described in Section 6.6, the Site has been divided into separate soil exposure areas based on current or future land use, former operations, waste types and source materials, and property boundaries. Both the nature and extent evaluation and this HHRA use these exposure area groupings. Figure 6-3 shows the locations of the exposure areas for soil and Table 6-8 summarizes their characteristics.

The results of this baseline HHRA will be used to assist risk managers (that is, EPA) in deciding how to protect humans from contaminants at the Site. Ecological risks are addressed in the ecological risk assessment, described in Section 10.

9.1 Organization of this Baseline Human Health Risk Assessment

This baseline HHRA includes the following components:

- **Section 9.2, Human Health Risk Assessment Guidance,** lists the guidance used for the HHRA.
- **Section 9.3, Selection of COPCs for Human Health,** describes the process implemented to select the data used in the HHRA and identify the COPCs for environmental media that are potentially accessible for human exposures.
- **Section 9.4, Human Exposure Assessment,** identifies the pathways by which potential human exposures could occur, describes how they are evaluated, and evaluates the magnitude, frequency, and duration of these potential exposures.
- **Section 9.5, Toxicity Assessment for Human Health,** summarizes the toxicity of the selected COPCs and the relationship between the magnitude of exposure and the occurrences of adverse health effects.
- **Section 9.6, Human Health Risk Characterization,** integrates information from the exposure and toxicity assessments to characterize the risks to human health from potential exposure to chemicals in environmental media.

- **Section 9.7, Summary of the HHRA Results,** provides a brief description of the results of the HHRA.
- **Section 9.8, Uncertainties Associated with the HHRA,** summarizes the basic assumptions used in the HHRA, as well as limitations of data and methodology for this assessment.

9.2 Human Health Risk Assessment Guidance

Guidance documents used in the preparation of the HHRA included the following:

- *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part A (Interim Final)* (EPA, 1989)
- *Soil Screening Guidance: User's Guide, Second Edition* (EPA, 1996)
- *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment, Final)* (EPA, 2004b)
- *Guidelines for Carcinogen Risk Assessment* (EPA, 2005a)
- *Framework for Metals Risk Assessment* (EPA, 2008a)
- *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)* (EPA, 2009a)
- *ProUCL Version 5.0.00 Technical Guide, Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations* (EPA, 2013c)
- *Exposure Factors Handbook 2011 Edition, Final* (EPA, 2011a)
- *Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors* (EPA, 2014)

9.3 Selection of COPCs for Human Health

The COPCs for human health at the Site are those chemicals that are carried through the risk assessment process. This section summarizes the chemicals detected in environmental media at the site and identifies the COPCs that are potentially accessible for human exposures. For this HHRA, the COPCs were evaluated to identify and eliminate from further consideration those contaminants that are unlikely to contribute substantially to overall risks at the site.

9.3.1 Data Used in the Baseline HHRA

Analytical data from the following investigations were used in this Baseline HHRA:

- 2002 PA/SI of the Former Iron King Mine property (ADEQ, 2002)
- 2004 PA/SI of the Former Humboldt Smelter property (ADEQ, 2004)
- 2005 EPA Removal Assessment (E & E, 2005)
- 2008 Ironite Products Company/NAI Sampling (Brown and Caldwell, 2009b)
- 2008 to 2009 Initial RI (EA, 2010)
- 2010 Supplemental RI (EA, 2011)
- 2012 to 2013 Background and Surface Soil Sampling (EPA, 2012b)
- 2013 to 2014 Data Gap RI (Lockheed Martin SERAS, 2015)

These pre-NPL and RI investigations are described in Sections 3 and 4. The methodology used to compile these data, and the data reduction procedures, are outlined in Section 6.1, Data Usability and Processing, and, more specifically, Section 6.1.3.4. As noted in Section 6, soil removal actions were performed at selected residential and municipal properties in 2006, 2007, and 2011.Because the removed media no longer contribute to risk associated with the Site, pre-removal concentrations in these locations are excluded from the HHRA.

The data from these investigations, which were included in this HHRA, were determined to be of suitable quality for assessing risk, and adequate for reliable risk management decisions for the Site.

The HHRA used analytical data collected from the following environmental, or exposure, media:

- Soil (from 0 to 2 feet bgs)
- Ambient air
- Agua Fria River sediment (from 0 to 0.5 foot below sediment surface [bss])
- Agua Fria River surface water

Groundwater data were not evaluated as part of the HHRA because: 1) site-related impacts to groundwater appear to be confined to the former Iron King Mine and Humboldt Smelter properties and the area between them; and 2) regional groundwater quality includes naturally elevated arsenic, and local domestic water quality may be affected by septic systems and other non-mine related activities (see Section 5.5.6 and Section 7.6).

Table 9-1 lists the exposure areas defined in Section 6 that were considered in the HHRA for each of the exposure media that were included, along with the human health exposure scenario evaluated for each. Figure 6-3 shows the exposure areas. Information about the samples used in the HHRA is provided, by medium, in the sections below.

9.3.1.1 Soil Samples

Data used for this HHRA include soil data collected as part of site investigations between 2002 and 2015, including data from soil collected at the mine and smelter properties and adjacent areas, residential properties, and regional soil samples. Soil sample locations are shown on Figures 3-1A and 3-1B and Figures 4-1A through 4-1D.

Observations made during these investigations have indicated that, when compared with surface soil sample data, the deeper soil samples have lower concentrations (near or below background values) of arsenic and lead. The soil background study performed as part of the RI (see Soil Background Study Report – Appendix E) indicated that in the APSI, concentrations of these metals are consistently higher (by greater than 2.5-fold) in soil samples collected from the surface compared to those from deeper underground. This is consistent with the understanding that site-related impacts very near the surface are likely a result of particulate migration or surface water transport, rather than background conditions. Given these findings, this HHRA focuses on data from surface soil samples collected from an interval of 0 to 2 feet bgs. Data from over 13,000 soil samples from this depth interval were collected during these investigations and used for this HHRA. The samples used are listed in Appendix K1, Tables K1-1 through K1-4, with the sample dates, depth intervals, and sample property groups.

9.3.1.2 Ambient Air Samples

In the Initial RI (2008-2009), EPA conducted ambient air sampling to determine the sources and potential offsite migration of airborne contamination. In August 2008, EPA collected approximately 90 ambient air samples (up to 6 stations per day for 5 days over 3 weeks) using BGI PQ100 samplers. From December 2008 through September 2009, EPA collected approximately 140 24-hour ambient air samples on a 6-day rotating basis, also using BGI PQ100 samplers. Metals analysis was conducted on the TSP samples. Results from these sampling events were considered collectively for this HHRA. Results from samples, which were collected using a continuous particulate monitor TEOM, were not used to assess chronic inhalation exposure and risk, because these samplers were intended to only characterize high wind events, and were biased to only include sampling when specified TSP thresholds were exceeded. As a result, they include only high-end episodic events, which are not considered representative of the chronic exposure conditions that are assumed for this HHRA.

Ambient air data used in this HHRA included data from 224 samples collected from 9 monitoring stations in 2008 and 2009, as listed in Table K1-5 of Appendix K1. The ambient air monitoring station locations are shown on Figure 4-6.

9.3.1.3 Agua Fria River Sediment Samples

Freshwater sediment data used in this HHRA included data from 38 grab samples, collected from 0 to 0.5 foot bss) in the Agua Fria River, as listed in Table K1-6 of Appendix K1. Samples were collected in 2002 as part of the PA/SI for the former Iron King Mine property, in 2008 to 2009 as part of the Initial RI, and in 2014 as part of the data gap RI. Sediment sample locations are shown on Figures 3-2 and 4-3.

9.3.1.4 Agua Fria Surface Water Samples

Surface water data used in the HHRA included data from 81 grab samples collected from the Agua Fria River, as listed in Table K1-7 of Appendix K1. Samples were collected in 2004 as part of the PA/SI for the former Humboldt Smelter property, in 2008 to 2009 as part of the initial remedial investigation, and in 2014 as part of the data gap RI. Sample locations are shown on Figures 3-3 and 4-4.

9.3.2 Data Reduction Procedures

The following rules were applied to identify data for use in in this RI, including the HHRA (for more detail; see Section 6.1):

- Estimated values (flagged with “J” qualifiers) were treated as detected concentrations.
- Rejected data (flagged with “R” qualifiers) were not used.
- Results with final validation qualifiers containing a “U” or “UJ” were considered not detected
- For duplicate samples, the following procedure was applied:
  - If there were multiple detections, the highest concentration was used so that the higher level of exposure was represented.
  - If there was only one detection and the other results were nondetections, the detected value was used.
  - If there were only nondetections, the result associated with the lowest (most sensitive) detection limit was used.

For more information on the development of the dataset used in the HHRA, refer to Section 6.1.3.4. When x-ray fluorescence data are available, their use for the HHRA is described in the following paragraphs.

9.3.2.1 Use of X-Ray Fluorescence Data for Risk Assessment

Soil metals/metalloids data used for this HHRA include results from both certified laboratory analyses and samples analyzed in the field by portable XRF spectroscopy. Sampling protocols for XRF analysis included the periodic collection of paired samples for laboratory analysis. As described in Section 6.1, linear regression analyses were performed on the paired samples to determine whether the XRF data reliably correspond to measured laboratory data. Correlation and regression analyses were used to compare XRF and laboratory data for arsenic, chromium, copper, iron, lead, manganese, and zinc, and develop adjustment equations for application to measured XRF data to make them correspond to expected laboratory results. These adjusted data were subsequently incorporated into the Site database. The HHRA only uses the adjusted XRF data when corresponding laboratory results at that location are not available.

These regression-based adjustments were designed to account for inherent differences between the two methods. They were performed not only to generate a consistent dataset, but also to allow for substantially greater geographic coverage and density of the analytical results. Refer to Appendix E for a detailed description of the correlation and regression procedures. The results indicated that the correlation coefficients for arsenic, iron, lead, manganese, and zinc were close to or greater than 0.9, indicating good correspondence between XRF and laboratory data. The correlation coefficients for chromium and copper, however, indicated the lack of a strong association between the XRF and laboratory values. The correlation coefficient for chromium was less than 0.5 and the correlation coefficient for copper was less than 0.3. As a result, XRF data from the RI were adjusted for arsenic, iron, lead, manganese, and zinc, but only laboratory data for chromium and copper were included[2] in the HHRA.

9.3.3 Process for Selection of Chemical of Potential Concern

All chemicals that were detected in the samples analyzed for a specific exposure medium (such as soil, ambient air, sediment, or surface water) and a specific exposure area were evaluated to identify those to be included as COPCs in the HHRA. For soil and sediment, a risk-based screening was conducted as the first step to eliminate chemicals from being selected as COPCs. If the maximum detected concentration within an exposure area was above the EPA RSL (EPA, 2015a), equating to $1x10^{-6}$ risk for carcinogens, or an HQ of 0.1 for noncarcinogens, then that chemical was identified as a COPC and included in the HHRA. The results of the risk-based screening for soil and sediment COPCs for each of the sample property groups are provided in Appendix K2, Tables K2-1 through K2-5. For ambient air and surface water data, risk-based screening was not conducted; instead, any detected chemical was considered a COPC for these media and included in the HHRA.

Essential nutrients are those chemicals considered essential for human nutrition. Chemicals considered essential nutrients were also eliminated as COPCs. Recommended daily allowances are developed for essential nutrients to estimate safe and adequate daily dietary intakes (National Academy of Sciences, 1989). Because calcium, magnesium, potassium, and sodium are considered naturally occurring essential nutrients and are generally recognized as being of low toxicity, they were excluded from further consideration as COPCs.

Of particular interest at mine sites is the contribution of natural levels of metals in the environment to the levels of total metals that were released to the environment during mining activities. Because mining occurs at locations that are naturally rich in metal ores, it is important to distinguish metals that are naturally present from those metals that were released from mining activities. The description of the process for defining the APSI and identifying background concentrations for metals in soil at the Site is described in Section 6.2 and in the Soil Background Study Report in Appendix E. Consistent with EPA guidance (EPA, 2002a), no COPCs were eliminated from the HHRA based on comparison to background concentrations. Instead, potential risks attributable to background concentrations are discussed in the section on risk characterization. To allow for the interpretation of natural background contributions to risk estimates within the APSI, the incremental risk above the risk attributable to background is estimated for each soil exposure area, as discussed in Section 9.6.4.

9.3.4 COPCs Selected for the HHRA

The COPCs selected for each exposure medium and exposure area at the Site are provided in Appendix K3, Tables K3-1 through K3-7. The summary statistics for each medium and data group considered in the HHRA are also provided in these tables. The primary contaminant groups identified as COPCs at the Site are metals, but also include polycyclic aromatic hydrocarbons (PAHs) and dioxin/furan compounds in some of some areas influenced by historic smelter operations.

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[2] Although using only laboratory data results in less coverage and density for these two metals, chromium and copper are not considered primary risk drivers for the Site.

9.4 Human Exposure Assessment

This section describes the means by which humans at or near the Site may come into contact with contaminants in environmental media. In addition, it addresses exposures to humans that may result under reasonably anticipated potential uses of the site in the future.

An exposure pathway can be described as the physical course that a COPC takes from the point of release to a receptor (humans). Chemical intake or route of exposure is the means by which a COPC enters a receptor. For an exposure pathway to be complete, all the following components must be present. These are:

- A source
- A mechanism of chemical release and transport
- An environmental transport medium
- An exposure point
- An exposure route
- A receptor or an exposed population (currently existing or that may exist in the future)

In the absence of any one of these components, an exposure pathway is considered incomplete and, by definition, there is no risk.

The primary sources of contamination, release and transport mechanisms, and media of concern are described in previous sections of this RI Report. Section 9.4.1 describes potentially complete human exposure pathways and receptors, based on current and reasonably anticipated future land uses for the site (described in Section 5.7). Figure 9-1 shows the conceptual exposure model for human exposure pathways at the Site.

9.4.1 Potentially Complete Human Exposure Pathways and Receptors

Based on the current understanding of land and water use conditions at or near the Site (as depicted on Figure 9-1), the most plausible current or future human receptor populations include the following:

- Current or future residents
- Current or future occupational workers
- Intermittent recreational visitors (for example, hikers)

As a result of the mix of current and projected future property ownership and uses on and near the Site, some receptor groups are considered more hypothetical for some properties (for example, where residents or workers do not currently exist but are not precluded by anticipated land use planning) than for other properties (for example, those with current residences or workplaces). As a conservative measure, this HHRA includes evaluation of an unrestricted residential exposure scenario for all soil exposure areas. Although future residential land use is not anticipated at some exposure areas, this scenario is included to determine whether land use restrictions may be needed. If risk estimates under unrestricted land use assumptions were found to be acceptable for that property, then no land use controls would be deemed necessary.

The exposure scenarios evaluated in the HHRA are described in the following subsections. Specific exposure assumptions used for each exposure scenario are provided in Table 9-2.

9.4.1.1 Residential Exposure Scenario

Current and future residents living at or near the Site are evaluated for potential exposure to COPCs detected in the following exposure media:

- Surface soil (0 to 2 feet bgs)
- Dusts in ambient air

Direct Contact with Soil. Potential routes of residential exposure to COPCs in surface soil include incidental ingestion, dermal contact, and inhalation of localized ambient dusts and vapors (collectively referred to as "direct contact with soil"). Current or future residents are evaluated as a combined child and adult, assumed to be exposed for 350 days per year over a duration of 26 years, with the first 6 years as a 15-kg child, and the following 20 years as an 80-kg adult. For evaluations of noncancer effects, both combined child/adult and child-only scenarios are considered. It should be recognized that the child-only scenario is a more health-conservative evaluation that is included for informational purposes to provide EPA with added input for determining borderline decisions for remediating specific properties at the Site. A site-specific uncertainty analysis, considering the results of the child-only scenario, is provided in Section 9.8; Uncertainties Associated with this Baseline HHRA.

Exposure to Ambient Dusts. The potential route of residential exposure to COPCs detected in ambient dusts is by direct inhalation. The data from ambient air sampling stations (see Section 9.3.1.2) are directly used for this assessment, and presumably include dusts regionally transported across multiple properties (and not necessarily associated with specific properties)[3]. Current or future residents are assumed to be exposed for 24 hours per day, 350 days per year, over a duration of 26 years.

A qualitative evaluation of potential residential exposure to homegrown produce is also provided in Section 9.6.5.1.

9.4.1.2 Occupational Worker Exposure Scenario

The Site includes properties currently zoned for or that could potentially be used for industrial or commercial uses. For the purposes of the HHRA and given these identified land uses, it is assumed that occupational workers would work at properties that are not currently zoned or used as residential. Current and future workers at or near the Site are evaluated for potential exposure to COPCs detected in soil only. Although outdoor worker exposure to dusts in ambient air is also possible, this medium is evaluated under the more health-protective residential scenario.

Direct Contact with Soil. Potential routes of worker exposure to COPCs in surface soil include incidental ingestion, dermal contact, and inhalation of localized ambient dusts and vapors. The current or future occupational worker is assumed to be an 80-kg adult, exposed to soil for 250 days per year over a duration of 25 years.

9.4.1.3 Recreational Visitor Exposure Scenario

The recreational visitor exposure scenario addresses individuals engaged in recreation (such as hiking, biking, hunting, wading, and swimming) on properties that are not currently zoned or used as residential, and are evaluated for potential exposure to COPCs detected in the following exposure media:

- Surface soil (0 to 2 feet bgs)
- Agua Fria River sediment (0 to 0.5 foot bss)
- Agua Fria River surface water

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[3] This assessment is distinct from the inhalation exposure component of direct contact with soil, which estimates exposure from localized ambient dust and vapors assumed to be originating from the soil at a specific property. Any dusts that may have historically been transported to current or future residential properties are therefore addressed as part of the assessment of direct contact of residential soil.

Direct Contact with Soil/Sediment. Potential recreational exposure to surface soil (0 to 0.5 foot bgs) and surface sediment (0 to 2 feet bss) are evaluated under this scenario. Potential routes of exposure include incidental ingestion, dermal contact, and inhalation of localized dusts and vapors. Exposure assumptions for an early adolescent-aged recreational visitor are used. The recreational visitor is assumed to be a 36-kg adolescent (10-year-old), exposed for 2 hours per day for 52 days per year, over a duration of 9 years. The assumption that a recreational visitor accesses the site once per week all year long is considered reasonably protective.

Direct Contact with Surface Water. Potential routes of exposure to surface water include incidental ingestion and dermal contact during wading or swimming activities. Exposure assumptions for an early adolescent-aged recreational visitor are used, including an incidental ingestion rate of 0.05 liter (L)/day and a skin surface area that includes the entire body. The recreational visitor is assumed a 36-kg adolescent (10-year-old) exposed for 52 days per year, over a duration of 9 years, with swimming occurring for a total of 1 hour per event.

9.4.2 Exposure Point Concentrations

An EPC is defined as the average concentration contacted at identified exposure points over the duration of an exposure period (EPA, 1992). EPA recommends using the average concentration to represent “a reasonable estimate of the concentration likely to be contacted over time” (EPA, 1989). To account for uncertainty and avoid underestimating contaminant exposure, the 95 percent UCL of the mean is typically used in CERCLA risk assessments to represent the average concentration. The UCL is defined as a value that, when calculated repeatedly for randomly drawn subsets of data, equals or exceeds the true population mean 95 percent of the time. Use of the UCL can also help account for uncertainties that can result from limited sampling data and/or the uneven spatial distribution of contaminant concentrations. Ideally, however, representative sampling should be conducted.

The EPCs for exposure pathways associated with the Site are estimated, where appropriate, by aggregating concentration data from media samples collected over a relevant exposure area. The EPCs for aggregate risk estimation are calculated by using the best statistical estimate of an upper bound on the average exposure concentrations, in accordance with EPA guidance for statistical analysis of monitoring data (EPA, 1989, 1992, and 2002a). When sufficient data are available, EPCs are calculated for each analyte using EPA’s statistical program ProUCL, Version 5.0 (EPA, 2013a). This procedure identifies the statistical distribution type (that is, normal, lognormal, or nonparametric) for each constituent within the defined exposure area (the area of interest) and computes the corresponding 95 percent UCL for the identified distribution type. Generally, at least 8 to 10 samples are needed to compute a meaningful UCL. Consistent with EPA guidance (EPA, 1989), the maximum detected concentration is used as the EPC in place of the 95 percent UCL when the number of detected values is small and the calculated 95 percent UCL is greater than the maximum detected value. However, using maximum detected values for EPCs may, in some cases, contribute to overestimation of risk. If a maximum value is used and found to contribute substantially to risk, the associated uncertainties would be addressed in the uncertainty section of this HHRA. However, this condition did not occur for this HHRA. The ProUCL output files for each of the evaluated exposure areas and media are provided in electronic format as Appendix K4.

For lead in soil, EPA guidance indicates that the arithmetic mean should be used as the concentration term when modeling blood-lead levels in children and adults (EPA, 2015b and 2015c). For this HHRA, both the mean and 95 percent UCL concentration of lead for each exposure area are compared to the risk-based screening levels described in Section 9.6.3. When a UCL is used, the result could be interpreted as a more conservative estimate of the risk of an elevated blood-lead level.

9.4.3 Human Exposure Areas

Exposure areas are those geographic areas over which investigation data are aggregated for computation of UCLs, and where independent estimates of risk are quantified. Implicit in the exposure area concept is the assumption that the receptor has equal likelihood of exposure to contamination at any individual location within the identified exposure area. In most cases, the exposure area was defined by a residential, or other type of, property boundary. However, because of the large geographic scale of some properties (for example, Iron King Mine and the Humboldt Smelter) and the possibility that some receptor types could be exposed over smaller areas, such properties were subdivided into more than one exposure area for the HHRA. Factors considered when defining the exposure areas included:

1. Locations that are plausibly visited or used by people over the assumed duration of exposure
2. Locations where RI data indicate the highest levels of contamination exist (for example, near the historical sources and releases)
3. Areas with sufficient numbers of samples to provide reliable estimates of exposure

Exposure areas can also be operationally defined to consider areas where independent risk management decisions and/or evaluations of feasible response actions are desired. In addition, the presence of physical barriers that might affect access or choices of where people might go (for example, the location of Agua Fria River, or segments of gulches), is also a consideration. Based on these criteria, each of the exposure areas for soil has been delegated to one of four current property types:

- Residential Yard-Specific Risk (RYSR)
- Residential Screening Area Risk (RSAR)
- Non-Residential/Possible Future Residential
- Non-Residential

For sediment and surface water, the following exposure areas are evaluated:

- Agua Fria River – Upstream of Smelter
- Agua Fria River – Adjacent to Smelter
- Agua Fria River – Downstream of Smelter

The exposure areas identified for the HHRA are summarized in Table 9-1 for each exposure medium. Figure 6-3 shows the locations of the exposure areas for soil; Figure 9-2 shows the locations for Agua Fria River surface water and sediment.

As described in Sections 6.6.23 and 7.3, sampling was performed and data evaluated on a yard-by-yard basis in the RYSR exposure areas. Small parcels were locally combined into single yards for sampling and risk evaluation. Larger properties were divided into smaller yards. The terms “yard” and “property” are used interchangeably in this HHRA.

As noted in Sections 6.6.24 and 7.3, eight of the exposure areas are designated as RSAR properties. They are each composed of several distinct residential properties. The combining of data from several representative residential properties into a larger RSAR area is considered appropriate because these areas are located near the boundaries of APSI and, therefore, are considered least likely to have been historically impacted by wind-blown releases from mine and smelter sources. The RSAR area locations are shown as highlighted in pink on Figure 6-3. Within the exposure area designated as RSAR-D, a stormwater diversion berm known to be made using imported mine tailings was identified as a hot spot during field investigations in 2014. As a result, the hot spot area is considered separately from the remainder of RSAR-D in this HHRA.

9.4.4 Estimation of Chemical Intake

Exposure that is normalized over time and body weight is termed intake (expressed as milligrams of chemical per kilogram body weight per day [mg/kg-day]). This section describes the equations that are used to calculate human exposures to chemicals found in soil, ambient air, sediment, and surface water.

The estimation of exposure requires numerous assumptions to describe potential exposure situations. A mixture of average and upper-bound exposure assumptions are used to estimate reasonable maximum exposure (RME) conditions to provide a bounding estimate on exposure. The exposure assumptions used for the HHRA are: specific to the identified exposure scenarios at the Site, selected based on the conceptual exposure models (Figure 9-1), and consistent with the current and reasonably anticipated future land uses. The exposure assumptions used for the HHRA are provided in Table 9-2. The equations used to calculate chemical intake and exposure concentrations associated with the various human exposure scenarios for the Site are provided in the following sections.

9.4.4.1 Incidental Ingestion of Soil or Sediment

The following age-weighted equation is used to calculate the intake (expressed as mg/kg-day) associated with the incidental ingestion of carcinogenic and noncarcinogenic chemicals in soil or sediment for the combined child/adult residential exposure scenario:

$$Intake = \frac{C_s \times IFS_{adj} \times BF \times EF \times 10^{-6}\, kg/mg}{AT}$$

Where:

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} + \frac{ED_a \times IRS_a}{BW_a}$$

And where:

C_s = chemical concentration in soil or sediment (mg/kg)
IFS_{adj} = age-adjusted soil/sediment ingestion factor (mg-year/kg-day)
BF = bioavailability adjustment factor
IRS_a = adult soil/sediment ingestion rate (milligrams per day [mg/day])
IRS_c = child soil/sediment ingestion rate (mg/day)
EF = exposure frequency (days/year)
ED_a = adult exposure duration (years)
ED_c = child exposure duration (years)
BW_a = adult body weight (kilograms [kg])
BW_c = child body weight (kg)
AT = averaging time (days)

The following equation is used to calculate the intake associated with the incidental ingestion of carcinogenic and noncarcinogenic chemicals in soil or sediment for the child-only residential (noncarcinogens only), occupational worker, and recreational visitor exposure scenarios:

$$Intake = \frac{C_s \times IRS_{c/a/ad} \times BF \times 10^{-6}\, kg/mg \times EF \times ED_{c/a/ad}}{BW_{c/a/ad} \times AT}$$

Where:

IRS_{ad} = adolescent soil/sediment ingestion rate (mg/day)
ED_{ad} = adolescent exposure duration (years)
BW_{ad} = adolescent body weight (kg)

The exposure assumptions for estimating chemical intake from the ingestion of chemicals in soil and sediment are provided in Table 9-2.

9.4.4.2 Dermal Contact with Soil or Sediment

The following age-weighted equation is used to calculate the intake from dermal contact with carcinogenic and noncarcinogenic chemicals in soil or sediment for the combined child/adult residential exposure scenario:

$$Intake = \frac{C_S \times SFS_{adj} \times ABS \times EF \times 10^{-6}\, kg/mg}{AT}$$

Where:

$$SFS_{adj} = \frac{ED_c \times AF_c \times SA_c}{BW_c} + \frac{ED_a \times AF_a \times SA_a}{BW_a}$$

And where:

C_s = chemical concentration in soil or sediment (mg/kg)
SFS_{adj} = age-adjusted dermal contact factor [(mg-year)/(kg-day)]
ABS = absorption efficiency (chemical-specific; see Table 9-3)
SA_a = adult exposed skin surface area (square centimeters [cm^2])
SA_c = child exposed skin surface area (cm^2)
AF_a = adult soil/sediment-to-skin adherence factor (mg/cm^2)
AF_c = child soil/sediment-to-skin adherence factor (mg/cm^2)
EF = exposure frequency (days/year)
ED_a = adult exposure duration (years)
ED_c = child exposure duration (years)
BW_a = adult body weight (kg)
BW_c = child body weight (kg)
AT = averaging time (days)

The following equation is used to calculate the intake from dermal contact with carcinogenic and noncarcinogenic chemicals in soil or sediment for the child-only residential (noncarcinogens only), occupational worker, and recreational visitor exposure scenarios:

$$Intake = \frac{C_S \times ABS \times SA_{c/a/ad} \times AF_a \times EF \times ED_{c/a/ad} \times 10^{-6}\, kg/mg}{BW_{c/a/ad} \times AT}$$

Where:

SA_{ad} = adolescent exposed skin surface area (cm^2)
AF_{ad} = adolescent soil/sediment-to-skin adherence factor (mg/cm^2)

The exposure assumptions for estimating exposure from dermal contact with soil and sediment are provided in Table 9-2. Chemical-specific dermal absorption factor values were obtained from EPA's supplemental guidance for dermal risk assessment (EPA, 2004b); these values are included in Table 9-3.

9.4.4.3 Inhalation of Dust and Vapors from Localized Soil

For each exposure area, localized dust and vapor concentrations in air were estimated from soil data using modeling approaches. In accordance with EPA (2009), the exposure concentration from inhalation of fugitive dust emissions originating from localized soil for the residential, occupational worker, and recreational visitor exposure scenarios is estimated using the following equation:

$$EC_a = \frac{C_s \times \left(\frac{1}{PEF} + \frac{1}{VF} \right) \times ET \times EF \times ED}{AT}$$

Where:

EC_a = exposure concentration in air (milligrams of substance per cubic meter of air [mg/m^3])
C_s = chemical concentration in soil (mg/kg)
ET = exposure time (unitless fraction of day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
PEF = particulate emission factor (cubic meters per kilogram [m^3/kg])
VF = volatilization factor (m^3/kg)
AT = averaging time (days)

The volatilization factors (VFs) for volatile COPCs in soil are calculated using the Jury Model presented in EPA soil screening guidance (EPA, 1996) and were obtained from EPA RSL tables (EPA, 2015a). The exposure assumptions used to estimate exposure from inhalation of dust originating from localized soil are provided in Table 9-2.

9.4.4.4 Inhalation of Dust Monitored in Ambient Air

For the residential exposure scenario, the exposure concentration from inhalation of metals in dust directly measured at ambient air monitoring stations during the RI is estimated using the following equation:

$$EC_a = \frac{C_a \times ET \times EF \times ED}{AT}$$

Where:

EC_a = exposure concentration in air (mg/m^3)
C_a = chemical concentration in air (mg/m^3)
ET = exposure time (unitless fraction of day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
AT = averaging time (days)

The exposure assumptions used to estimate exposure from inhalation of ambient air are provided in Table 9-2.

9.4.4.5 Incidental Ingestion of Surface Water

The following equation is used to estimate the intake associated with the incidental ingestion of carcinogenic and noncarcinogenic chemicals in surface water for the recreational visitor exposure scenario:

$$Intake = \frac{C_w \times IWR_{ad} \times EF \times ED_{ad}}{BW_{ad} \times AT}$$

Where:

C_w = chemical concentration in surface water (mg/L)
IRW_{ad} = adolescent surface water ingestion rate (L/day)
EF = exposure frequency (days/year)
ED_{ad} = adolescent exposure duration (years)
BW_{ad} = adolescent body weight (kg)
AT = averaging time (days)

The exposure assumptions for estimating chemical intake from the ingestion of surface water are provided in Table 9-2.

9.4.4.6 Dermal Contact with Surface Water

The following equation is used to calculate the intake associated with dermal contact with carcinogenic and noncarcinogenic chemicals in surface water for the recreational visitor exposure scenario:

$$Intake = \frac{C_w \times SA_{ad} \times ED_{ad} \times K_p \times EF \times ET_w \times CF}{BW_{ad} \times AT}$$

Where:

C_W = chemical concentration in water (mg/L)
SA_{ad} = adolescent exposed skin surface area (cm^2)
ED_{ad} = adolescent exposure duration (years)
K_p = dermal permeability coefficient (cm/hour)
EF = exposure frequency (days/year)
ET_w = swimming/wading exposure time (hour)
CF = conversion Factor (0.001 L/cubic centimeter)
BW_{ad} = adolescent body weight (kg)
AT = averaging time (days)

The exposure assumptions used to estimate exposure from dermal contact with surface water are provided in Table 9-2. Chemical-specific dermal permeability coefficients (Kp) were obtained from the Oak Ridge National Laboratory (ORNL) Risk Assessment Information System (ORNL, 2015a), calculated using EPA's Dermwin tool, which is part of its Estimation Program Interface Suite program (EPA, 2011b).

9.4.4.7 Calculation of Intake for Mutagenic COPCs

The scientific community has recognized early-in-life susceptibility to carcinogens as a public health concern. In its revised Cancer Assessment Guidelines, EPA concluded that risk assessment approaches of the time did not adequately address the possibility that exposures to a chemical in early life can result in higher lifetime cancer risks than a comparable duration adult exposure (EPA, 2005g). To address this potential for increased risk, EPA recommends use of a potency adjustment to account for early-in-life exposures.

When no chemical-specific data are available assess cancer susceptibility from early-life exposure, the following, default age-dependent adjustment factors are recommended for use when evaluating a carcinogen known to cause cancer through a mutagenic mode of action:

- Tenfold adjustment for exposures during the first 2 years of life
- Threefold adjustment for exposures from ages 2 to less than 16
- No adjustment for exposures after turning 16 years of age

As an example, the following equation is used to calculate the intake for mutagenic COPCs associated with the incidental ingestion of contaminants in soil or sediment:

$$Intake = \frac{C_s \times \left(\begin{array}{c} \frac{(ED_{0\text{-}2} \times IRS_c) \times 10}{BW_c} + \frac{(ED_{2\text{-}6} \times IRS_c) \times 3}{BW_c} + \\ \frac{(ED_{6\text{-}16} \times IRS_a) \times 3}{BW_a} + \frac{(ED_{16\text{-}26} \times IRS_a) \times 1}{BW_a} \end{array} \right) \times EF}{AT}$$

Where:

C_s = chemical concentration in soil or sediment (mg/kg)
IRS_a = adult soil/sediment ingestion rate (mg/day)
IRS_c = child soil/sediment ingestion rate (mg/day)
EF = exposure frequency (days/year)
$ED_{0\text{-}2}$ = exposure duration ages 0 to 2 (years)
$ED_{2\text{-}6}$ = exposure duration ages 2 to 6 (years)
$ED_{6\text{-}16}$ = exposure duration ages 6 to 16 (years)
$ED_{16\text{-}30}$ = exposure duration ages 16 to 26 (years)
BW_a = adult body weight (kg)
BW_c = child body weight (kg)
AT = averaging time (days)

Of the COPCs evaluated in this HHRA, EPA considers that there is sufficient weight-of-evidence to conclude that the carcinogenic PAHs and hexavalent chromium cause cancer through a mutagenic mode of action. Consideration of early-life stage exposure is limited to the residential and recreational exposure scenarios.

9.4.5 Oral Bioavailability Adjustment Factor for Arsenic

The issue of bioavailability of arsenic is especially important at mining, milling, and smelting sites. This is because the arsenic at these sites often exists, at least in part, as a poorly soluble sulfide, and may occur in particles of inert or insoluble material. These factors collectively tend to reduce the bioavailability of arsenic. The oral bioavailability of soil-bound arsenic largely depends on the rate at which it dissociates from the soil matrix in the gastrointestinal (GI) tract. Soil-bound arsenic is usually absorbed by the GI tract to a lesser degree than when in more soluble forms. This reduced absorption results from the affinity between arsenic and the soil matrix, the low solubility of the chemical form of arsenic associated with the soil, or both. Thus, the bioavailability of arsenic from Site soil is expected to be low for constituents that are tightly bound within the soil matrix and/or are in a form that is insoluble in the GI tract under physiological conditions.

During the RI, a site-specific bioavailability study was conducted to provide a better understanding of the oral bioavailability of arsenic in soil, which may have been affected by site-related releases. The ability of inorganic arsenic in these soils to be extracted under laboratory conditions that simulate physiological conditions (for example, gastric pH, buffering, and temperature) was demonstrated to provide a reliable surrogate for the relative bioavailability of arsenic from the soil. The results of the site-specific bioavailability study are provided in Appendix H. Using these results, this HHRA adjusts oral exposure to account for this reduced bioavailability.

A site-specific bioavailability adjustment factor was estimated using test results from 72 soil samples collected across the site from a combination of residential and non-residential areas (gulch areas, Humboldt Smelter area, and MTP). To provide a health-conservative estimate of site-specific bioavailability and in accordance with EPA practice, the 95th percentile value of 22.5 percent was selected as the site-specific oral bioavailability adjustment factor for use in this HHRA. This adjustment factor is used to adjust the oral exposure from total arsenic measured in all soil and sediment samples included in this HHRA. The test results indicate that the forms of arsenic in soil at the Site are of relatively low bioavailability, when compared to EPA default value of 60 percent (EPA, 2012a).

It should be noted that the oral bioavailability adjustment factor derived herein is intended to be a site-specific value, and is not intended for general use at other sites.

9.5 Toxicity Assessment for Human Health

The toxicity assessment component of the HHRA is composed of two steps: hazard identification and dose-response assessment. Hazard identification is the process of determining whether exposure to a chemical may result in a deleterious health effect in humans. It consists of characterizing the nature of the effect and strength of the evidence that the chemical will cause the observed effect. Dose-response assessment characterizes the relationship between the dose and the incidence and/or severity of the adverse health effect in the exposed population.

For risk assessment purposes, chemicals are generally separated into two broad groups based on their effects on human health: carcinogens and noncarcinogens. The primary basis for this classification is that health risks are calculated quite differently for cancer and noncancer effects, and separate toxicity values are developed for carcinogens and noncarcinogens. Carcinogens are those chemicals suspected of causing cancer following exposure; noncarcinogenic effects cover a wide variety of systemic effects, such as liver toxicity or developmental effects. Some chemicals (such as arsenic) are capable of eliciting both carcinogenic and noncarcinogenic responses; therefore, these carcinogens will also be evaluated for systemic (noncarcinogenic) effects. For the purposes of this HHRA, the term “risk” is used generically to include the outcomes associated with exposures to chemicals with either cancer or noncancer toxicity, unless otherwise specified.

9.5.1 Toxicity Values for Evaluating Noncancer Effects

The reference dose (RfD) and reference concentration (RfC) provide quantitative information for use in risk assessments for health effects known or assumed to be produced through a nonlinear (possibly threshold) mode of action. The RfD, expressed in units of mg/kg-day, is defined 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 inhalation RfC, expressed in units of mg/m^3, is analogous to the oral RfD, but provides a continuous inhalation exposure estimate, and considers toxic effects for both the respiratory system (portal of entry) and those peripheral to the respiratory system (systemic effects). The use of RfDs and RfCs is based on the concept that there is a range of exposures that exist up to a finite value, or threshold, which can be tolerated without producing a toxic effect. This HHRA uses available chronic RfDs and RfCs for the oral and inhalation exposure routes, respectively. Because EPA has not derived toxicity values specific to skin contact, dermal RfDs were derived in accordance with EPA’s supplemental guidance for dermal risk assessment (EPA, 2004b).

The RfD that reflects the absorbed dose was calculated by using the following equation:

$$RfD_{ABS} = RfD_{o} \times ABS_{GI}$$

Where:

RfD_{ABS} = absorbed reference dose
RfD_{o} = oral reference dose
ABS_{GI} = GI absorption efficiencies

EPA recommends adjusting oral toxicity values only when evidence suggests that GI absorption is less than 50 percent. GI absorption efficiencies were also obtained from the supplemental guidance for dermal risk assessment (EPA, 2004b); these are listed in Table 9-3.

9.5.2 Toxicity Values for Evaluating Cancer Effects

Oral cancer slope factors and inhalation unit risks are used to estimate the risk of cancer associated with exposure to a carcinogen. The oral slope factor represents an upper bound, generally approximating a 95 percent confidence limit, on the relationship between a dose of a carcinogen and the probability of contracting cancer from a lifetime exposure by ingestion. Slope factors are expressed in units of the reciprocal of milligram of substance/kilogram body weight-day (mg/kg-day^{-1}). An inhalation unit risk is an upper-bound excess lifetime cancer risk (ELCR) estimated to result from continuous exposure at a concentration of 1 µg/m^{3} in air.

In addition to the numerical estimates of carcinogenic potential, a cancer weight-of-evidence descriptor is used by EPA to describe a substance's potential to cause cancer in humans and the conditions under which the carcinogenic effects may be expressed. This judgment is independent of consideration of the agent's carcinogenic potency. Under EPA's 1986 Guidelines for Carcinogen Risk Assessment (EPA, 1986b), the weight-of-evidence was described by categories "A" through "E"—Group A for known human carcinogens through Group E for agents with evidence of noncarcinogenicity. Under the Guidelines for Carcinogen Risk Assessment (EPA, 2005a), a narrative approach, rather than the alphanumeric categories, is used to characterize carcinogenicity. Five standard weight-of-evidence descriptors are used:

- Carcinogenic to Humans
- Likely to Be Carcinogenic to Humans
- Suggestive Evidence of Carcinogenic Potential
- Inadequate Information to Assess Carcinogenic Potential
- Not Likely to Be Carcinogenic to Humans

Because EPA has not derived toxicity values specific to skin contact, dermal slope factors were derived in accordance with EPA's supplemental guidance for dermal risk assessment (EPA, 2004b). The slope factor that reflects the absorbed dose was calculated by using the following equation:

$$SF_{ABS} = \frac{SF_{o}}{ABS_{GI}}$$

Where:

SF_{ABS} = absorbed slope factor
SF_{o} = oral slope factor
ABS_{GI} = GI absorption efficiencies

Oral toxicity values should be adjusted only when evidence suggests that GI absorption is less than 50 percent. GI absorption efficiencies were also obtained from the supplemental guidance for dermal risk assessment (EPA, 2004b); these are listed in Table 9-3.

For the inhalation route, this HHRA uses the inhalation unit risk (IUR) to estimate risk in accordance with *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment)* (EPA, 2009a). EPA defines an IUR as “the upper-bound ELCR estimated to result from continuous exposure to an agent at a concentration of 1 µg/m^3 in air” (EPA, 2008b).

9.5.3 Sources of Toxicity Values

In accordance with EPA guidance (EPA, 2003a), toxicity values were obtained from the following sources in order of preference:

- The Integrated Risk Information System (IRIS) database is available through the EPA Environmental Criteria and Assessments Office in Cincinnati, Ohio (EPA, 2016). IRIS prepared and maintained by EPA, is an electronic database containing health risk and EPA regulatory information on specific chemicals.
- EPA provisional peer-reviewed toxicity values (PPRTVs) are provided by the Office of Research and Development, National Center for Environmental Assessment, Superfund Health Risk Technical Support Center, which develops these values on a chemical-specific basis when requested under the EPA Superfund program. PPRTVs were obtained from the EPA RSL tables (EPA, 2015a).
- Other sources of information may be used, with a preference for sources that provide toxicity information based on similar methods and procedures as those used for IRIS and PPRTV values, and contain values that are peer reviewed, available to the public, and transparent with respect to the methods and processes used to develop the values. Examples of recommended sources include, but are not limited to, the California Environmental Protection Agency, available at http://www.oehha.ca.gov/tcdb/, and the Agency for Toxic Substances and Disease Registry minimal risk levels, which represent estimates of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure.

The toxicity values used in this HHRA are listed in Table 9-3. Short toxicological summary fact sheets for some of the primary COPCs at the Site (arsenic and lead) are provided in Appendix L. These toxicity summary fact sheets (referred to as “ToxFAQs”) have been developed by the Agency for Toxic Substances and Disease Registry’s Division of Toxicology and are included for access by users as quick and easy-to-understand guides. Answers are provided to the most frequently asked questions about exposure to each hazardous substance and the effects of exposure on human health. A description of the uncertainties associated with the toxicity value used for the noncancer hazard assessment for arsenic is also provided in Section 9.8.4.

9.5.4 Toxicity Equivalency Factors for PAHs and Dioxins/Furans

An assessment of the cancer risk from long-term human exposure to chemical mixtures would best be conducted with quantitative information on the dose-response relationship from chronic exposure to the mixture of concern. However, this approach is really only feasible for mixtures of consistent composition that are produced by industrial processes. It is impossible to ascertain the toxicity of each of the innumerable permutations of highly variable environmental mixtures. Another approach may be used for mixtures of structurally similar chemicals that have a common toxicity mechanism, where the toxicity of each component of the mixture has been evaluated relative to an index compound. This approach has been employed for carcinogenic PAHs (cPAHs). Specifically, the toxicity of several cPAHs has been evaluated relative to an index compound, benzo[a]pyrene (B[a]P), using toxicity equivalency factors (TEFs) (EPA, 2000). For example, the cPAH, benz[a]anthracene, has 10 percent of the toxicity of B[a]P and is assigned a TEF of 0.1. Thus, a dose of benz[a]anthracene is the TEQ to a dose of B[a]P that is tenfold less.

The toxicity of a cPAH mixture may be expressed in terms of the toxicity of an equivalent concentration of B[a]P (such as, B[a]P TEQ), by multiplying the concentration of each cPAH by its TEF and then summing this product for all cPAHs in the mixture. The cancer risk posed by the mixture is then computed by multiplying the B[a]P TEQ value by the slope factor for B[a]P. This HHRA uses the TEFs developed by EPA's Environmental Criteria and Assessment Office (EPA, 1993a) to assess the potency of individual PAHs relative to B[a]P as follows:

PAH Compound	TEF
B[a]P	1
Benz(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.01
Chrysene	0.001
Dibenz(a,h)anthracene	1
Indeno(1,2,3-cd)pyrene	0.1

The cancer slope factors and inhalation unit risk factors for carcinogenic PAHs listed in Table 9-3 were weighted according to these respective TEFs.

TEQ concentrations for "dioxin-like" polychlorinated dibenzodioxins and polychlorinated dibenzofurans were calculated in accordance with the World Health Organization's TEF approach (Van den Berg, et al., 2006). The purpose of using the World Health Organization's TEF approach is to adjust the relative potency of dioxin-like PCBs, polychlorinated dibenzodioxins, and polychlorinated dibenzofurans relative to 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). This HHRA uses the following TEFs:

Chlorinated dibenzo-p-dioxins	TEF
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
Chlorinated dibenzofurans	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0003

The TEQ is computed for each sample using only the detected congeners in that specific sample. The EPC is then computed from TEQs for all samples within an exposure area, and the toxicity factors for 2,3,7,8-TCDD, listed in Table 9-3, are used for computing risk.

9.6 Human Health Risk Characterization

This section summarizes the approach used to develop the human health risk estimates for the Site and presents the quantitative risk characterization results for the soil, ambient air, sediment, and surface water samples used in the HHRA. In this risk characterization step, quantification of risk is accomplished by combining the results of the exposure assessment (estimated chemical intakes and exposure concentrations) with the results of the dose-response assessment (toxicity values identified in the toxicity assessment) to provide numerical estimates of potential human health risk. The approach differs for potential cancer and noncancer risks, as described in the following sections.

Although this HHRA 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. 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.

For the purposes of this assessment, human health risk is evaluated in accordance with EPA guidance (EPA, 1991a), using the following risk thresholds:

- In interpreting estimates of ELCR, EPA under the Superfund program generally considers action to be warranted when the multichemical aggregate cancer risk for all exposure routes within a specific exposure scenario exceeds 1 x 10^{-4}. Action generally is not required for risks falling within 1 x 10^{-6} and 1 x 10^{-4}; however, this is judged on a case-by-case basis. EPA may also consider the possibility that individuals may be exposed via multiple exposure scenarios in this analysis.
- Under EPA guidance, the potential for noncancer effects exists if the multichemical aggregate noncancer hazard for all exposure routes within a specific exposure scenario exceeds a target noncancer hazard index (HI) of 1 for toxicants that have similar mechanisms of action (that is, the same target organ/system). EPA may also consider the possibility that individuals may be exposed via multiple exposure scenarios in this analysis.
- If lead concentrations in environmental media result in a predicted blood-lead level of 10 micrograms per deciliter (µg/dL) in greater than 5 percent of the potentially exposed population,[4] then EPA recommends that actions be taken to significantly minimize or eliminate this exposure to lead.

9.6.1 Cancer Risk Estimation Method

The potential for cancer effects is evaluated by estimating ELCR. This risk is the incremental increase in the probability of developing cancer during one's lifetime over the background probability of developing cancer (if no exposure to site chemicals occurs). For example, an ELCR of 2 x 10^{-6} means that for every 1 million people exposed to the carcinogen throughout their lifetimes, the average incidence of cancer may increase by two cases of cancer. In the United States, the background probability of developing cancer for men is a little less than one in two, and for women is a little more than one in three (American Cancer Society, 2014). As previously noted, cancer slope factors developed by EPA represent upper-bound estimates; therefore, any cancer risks generated in this assessment should be regarded as an upper bound on the potential cancer risks. The actual cancer risk may be less than that predicted, and may be zero (EPA, 1989).

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[4] For the purposes of this HHRA, a soil concentration equal to 400 mg/kg is used as a risk threshold level for all exposure scenarios. This concentration meets the threshold of 10 µg/dL blood lead in greater than 5 percent of the potentially exposed population. It should be noted that a provisional value of 140 mg/kg is also considered in this HHRA, as described in Section 9.6.3.

ELCR is estimated by using the following formula:

$$Risk \quad = \quad Intake \quad x \quad SF$$

Where:

Risk = ELCR (unitless probability)
Intake = chronic daily intake averaged over a lifetime (mg/kg-day)
SF = cancer slope factor $(\text{mg/kg-day})^{-1}$

Inhalation risk is calculated by multiplying the exposure concentration by the IUR. The IUR is expressed in different units than the cancer slope factor (above). A conversion factor is necessary to normalize units between the IUR and exposure concentration values. Inhalation risk is estimated by using the following formula:

$$Risk_{inh} = EC_a \times IUR \times CF$$

Where:

$Risk_{inh}$ = ELCR from inhalation (unitless probability)
EC_a = exposure concentration in air (mg/m^3)
IUR = inhalation unit risk $(\mu\text{g/m}^3)^{-1}$
CF = conversion factor (microgram per milligram)

For cPAHs and hexavalent chromium, which have been identified as having a mutagenic mode of action, dose estimates are adjusted upwards in the risk calculation, as described in Section 9.4.4.7.

Although synergistic or antagonistic interactions might occur between cancer-causing chemicals and other chemicals, information is generally lacking in the toxicological literature to predict quantitatively the effects of these potential interactions. Therefore, cancer risks are treated as additive within an exposure route in this assessment. This approach is consistent with EPA guidelines for the health risk assessment of chemical mixtures (EPA, 1986a). For estimating the cancer risks from exposure to multiple carcinogens from a single exposure route, the following equation is used:

$$Risk_T = \sum_1^N Risk_i$$

Where:

$Risk_T$ = total cancer risk from route of exposure
$Risk_i$ = cancer risk for the i^{th} chemical
N = number of chemicals

For each potentially exposed population, cancer risks are estimated for individual exposure routes, as well as the total risks across all exposure routes.

9.6.2 Noncancer Risk Estimation Method

For noncancer effects, the likelihood that a receptor will develop an adverse health effect is estimated by comparing the predicted level of exposure for a particular chemical with the highest level of exposure that is considered protective (that is, its RfD). The ratio of the intake divided by RfD is the HQ:

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

Where:

HQ = noncancer hazard quotient from route of exposure
Intake = chronic daily intake averaged over the exposure duration (mg/kg-day)
RfD = noncancer reference dose (mg/kg-day)

For noncancer effects by inhalation exposure, the following equation is used:

$$HQ_{inh} = \frac{EC}{RfC}$$

Where:

HQ_{inh} = noncancer hazard quotient from inhalation
EC = exposure concentration in air (mg/m^3)
RfC = noncancer reference concentration (mg/m^3)

When the HQ for a chemical exceeds 1 (exposure exceeds the RfD or RfC), there is a concern for potential noncancer health effects. To assess the potential for noncancer effects posed by exposure to multiple chemicals, a HI approach was used, in accordance with EPA guidance (1989). This approach assumes that the noncancer hazard associated with exposure to more than one chemical is additive; therefore, synergistic or antagonistic interactions between chemicals are not accounted for. The HI may exceed 1, even if all the individual HQs are less than 1. In this case, the chemicals may be segregated by similar mechanisms of toxicity and toxicological effects. Separate HIs may then be derived based on mechanism and effect. The HI is calculated as follows:

$$HI = \frac{Intake_1}{RfD_1} + \frac{Intake_2}{RfD_2} + .\frac{Intake_i}{RfD_i}$$

Where:

HI = hazard index
$Intake_i$ = daily intake of the i^{th} chemical (mg/kg-day)
RfD_i = reference dose of the i^{th} chemical (mg/kg-day)

Both intake and RfD are expressed in the same units (mg/kg-day or, in the case of inhalation, the exposure concentration and RfC are expressed as mg/m^3) and represent the same exposure period (such as chronic exposure).

For each potentially exposed population, HIs are estimated for individual exposure routes, as well as the total HI across all exposure routes.

9.6.2.1 Tiered Approach for Evaluation of Noncancer Hazard Index

As a result of the large numbers of exposure areas evaluated for the Site, a tiered approach is used to evaluate noncancer HI. The purpose is to efficiently focus effort on those exposure areas where noncancer hazard is most likely to be identified. This tiered approach includes the following evaluation steps:

- Step 1 – Compute Site HIs (including all COPCs) for all exposure areas and all exposure scenarios.
- Step 2 – If the Site HI from Step 1 exceeds 1, compute the incremental HI as described in Section 9.6.4.
- Step 3 – If the incremental HI from Step 2 exceeds 1, conduct target organ/system HI segregation.

The results for each of these steps are provided in Section 9.6.5 for each of the exposure scenarios identified for the Site. For Step 3, the segregation of HIs into common critical target organ/system effects requires identification of which COPCs may have similar mechanisms of toxicity. Table 9-4 summarizes which COPCs have common endpoints, as identified from EPA’s IRIS database (EPA, 2016) or other sources listed in Section 9.5.3.

9.6.3 Risk Estimation Method for Lead

Potential adverse health effects from lead are evaluated using different methods than those conventionally used for other chemicals. This is because, for lead, most human health effects data are based on blood-lead concentrations rather than on the external dose. The adverse health outcomes, which include neurotoxic and developmental effects, may occur at exposures so low that they may be considered to have no threshold. EPA views it as inappropriate to develop noncarcinogenic threshold exposure levels (RfDs) for lead. Instead, an integrated exposure uptake biokinetic (IEUBK) model is used that relates exposure to measured lead concentrations in the environmental media with an estimated blood-lead level.

For this HHRA, potential adverse health effects from lead are evaluated by comparing the EPC for lead in soil and sediment to the following levels:

1. **The current EPA RSLs** (EPA, 2015a) – The soil RSL of 400 mg/kg for residential land use was derived by EPA using the IEUBK lead model (EPA, 2005e). The IEUBK model is designed to predict probable blood-lead concentrations, for children between 6 months and 7 years of age who have been exposed to lead through various sources (air, water, soil, diet, and *in utero* contributions from the mother). A predicted blood-lead level of 10 µg/dL in greater than 5 percent of the potentially exposed population is considered by EPA to be a level of concern. Blood-lead levels above this, therefore, trigger evaluation of whether actions should be taken to significantly minimize or eliminate exposure to lead. The soil RSL of 800 mg/kg for worker scenario was derived by EPA based on the adult lead model (ALM), version date June 21, 2009 (EPA, 2003b). The ALM develops a risk-based soil concentration that is protective of fetuses carried by women who may be exposed to lead.
2. **Provisional RSL** – In 2012, the Advisory Committee on Childhood Lead Poisoning Prevention (ACCLPP) conducted a critical review of available lead toxicity studies, and reported that the overall weight-of-evidence substantiates that neurocognitive decrements (as well as other adverse systemic effects, such as cardiovascular, immunological, and endocrine effects) can occur in children, even when blood-lead levels are below 10 µg/dL (ACCLPP, 2012). Based on the conclusion that blood-lead levels below 10 µg/dL can harm children, ACCLPP and Center for Disease Control (CDC) (CDC, 2007) have recommended that a revised reference value of 5 µg/dL blood lead be used to identify children with elevated blood-lead levels. This revised reference value is based on the 97.5th percentile of the blood-lead distribution in children aged 1 to 5 years, derived from the National Health and Nutrition

> Examination Survey. The National Toxicology Program (NTP) has reported that children aged 1 to 5 years consistently have higher blood-lead levels than do older children. NTP suggested this was likely because of hand-to-mouth activity in young children (NTP, 2012). Similarly, the CDC reported that several studies show a peak in children's blood-lead levels around 24 months of age (CDC, 2007). Neurological deficits have been associated with increased blood-lead levels among children in this age range (NTP, 2012). Given this information, the IEUBK lead model (build 11) was used to derive a provisional screening level for soil by considering the critical age group of 1 to 5 years (12 to 71 months) as better aligned with the most exposed population (NTP, 2012; EPA, 2013b), and using the revised blood lead reference value of 5 µg/dL as better aligned with CDC and lead science conclusions. Using these assumptions results in a 95 percent not to exceed provisional lead soil value of 140 mg/kg.

Lead concentrations detected in soil are compared to both the current RSLs and the provisional screening level in this HHRA to provide the range of potential for adverse effects from lead exposure, and allow for the most informed risk management decisions for the site. It should be noted that the provisional screening value has not been fully promulgated by EPA and is currently under review. As such, this value is not intended for general application at this time. The application of further regulatory developments related to risk assessment for lead exposure at the site will be revisited during the 5-year review process.

To evaluate the potential for adverse health effects from lead in surface water, the EPCs are screened against the EPA action level of 15 µg/L for lead in tap water. To evaluate the potential for adverse health effects from lead in ambient air, the EPCs are compared with the primary National Ambient Air Quality Standard (NAAQS) for lead (EPA, 2008c) of 0.15 µg/m^3.

9.6.4 Consideration of Risk Contribution from Natural Background

Consistent with EPA guidance (EPA, 2002a), no COPCs were eliminated on the basis of comparison to background concentrations. Instead, potential risks and hazards attributable to background levels of metals[5] are addressed in this HHRA by computing incremental site risks. Incremental risk is defined as that portion of the site risk in excess of that resulting from normal regional background/ambient concentrations of metals, and presumably attributable to site-related releases. Incremental risk is calculated as follows:

$$Incremental\ ELCR\ (or\ HI) = \ Site\ ELCR\ (or\ HI) - Background\ ELCR\ (or\ HI)$$

The incremental risk is computed for residential, occupational, and recreational exposure scenarios for soil only, for each of the identified exposure areas.

9.6.5 Summary of Risk Estimates by Exposure Scenario

This section summarizes the RME risk estimates for each of the exposure scenarios identified for the Site. These risk estimates assume RME conditions to provide health-protective estimates on exposure. As described previously, the exposure scenarios for the Site are as follows:

- Current or future residents
- Current or future occupational workers
- Intermittent recreational visitors (for example, hikers)

The cancer and noncancer risk estimates for potential exposure to COPCs in soil, ambient air, sediment, and surface water samples are summarized in Tables 9-5 through 9-18 for each of the property types, and described by exposure scenario in the following sections. For each potentially exposed population,

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[5] Because the primary carcinogen associated with site-related releases is arsenic, background risk only considered arsenic. For noncancer evaluations, background hazards from all hazard-driving metals are considered in the calculation of the incremental HI.

the site risks for each exposure area are estimated as the cumulative risks across all exposure routes (ingestion, dermal contact, and inhalation). For comparative purposes, and in accordance with EPA guidance (EPA, 2002a), incremental cancer and noncancer risk estimates are also provided. The risk calculation data sheets used to develop the risk summary tables for each exposure scenario described below are provided by in electronic format as Appendix K5.

9.6.5.1 Residential Exposure Scenario

Current or future residents at or near the Site are evaluated for potential exposure to COPCs detected in soil (0 to 2 feet bgs) and ambient air. The incremental cancer and noncancer risk estimates for each of these media are described in the following subsections. A qualitative evaluation of potential residential exposure to homegrown produce is also provided.

Residential Exposure to Soil

The following tables include the HI and ELCR estimates for residential exposure to soil, summarized by exposure area for the four current property types:

- Table 9-5 – RYSR
- Table 9-6 – RSAR
- Table 9-7 – Non-Residential/Possible Future Residential
- Table 9-8 – Non-Residential

The individual sample locations included for each exposure area are shown on maps provided in Appendix J and listed by exposure area in Appendix K1, Tables K1-1 through K1-4. EPCs are provided in Tables K3-1 through K3-4.

RYSR Properties – Figure 9-3 shows the results of the incremental residential ELCR estimates for the RYSR exposure areas. The numeric incremental ELCR estimates are provided in Table 9-5. Of the 384 exposure areas evaluated as RYSR properties, the incremental ELCR estimates are above the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} at 7 exposure areas, within the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} at 177 exposure areas, and at or below 1 x 10^{-6} at 200 exposure areas. The incremental ELCR is almost entirely contributed by arsenic for all exposure areas. The ELCR for background levels of arsenic is estimated to be 2 x 10^{-5}.

The residential HI estimates for the RYSR exposure areas for the combined child/adult exposure scenario are provided in Table 9-5. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the 384 exposure areas evaluated as RYSR properties, the HI estimates exceed the EPA HI threshold value of 1 at 67 exposure areas. These 67 exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of these 67 exposure areas, the incremental HI estimates exceed the EPA HI threshold value of 1 at 12 exposure areas (Table 9-5). These 12 exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-9 provides the HI results for the 12 exposure areas evaluated for target organ/system HI segregation. Of these 12 exposure areas, the target organ/system-specific HI estimates exceed the EPA HI threshold value of 1 at 4 exposure areas (exposure areas 120, 157, 1910, and 2615). The target organ/system-specific HIs are driven by elevated levels of arsenic[6] at exposure areas 157 and 2615, by elevated levels of antimony at exposure area 120, and by elevated levels of manganese at exposure area 1910.

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[6] See Section 9.8.4 regarding the uncertainties associated with the toxicity factor used for the noncancer hazard assessment for arsenic.

Three (exposure areas 120, 157, and 2615) of the four exposure areas with target organ/system-specific HI estimates exceeding 1 also have an estimated ELCR exceeding 10^{-4} and/or a lead EPC over the EPA residential screening level of 400 mg/kg.

The elevated levels of manganese present in soil at exposure area 1910 do not appear to be from mine- or smelter-related sources, and are further evaluated in Section 7.1.

Figure 9-4 shows the results of the residential HI estimates for the RYSR exposure areas, depicting those with target organ/system-specific HI estimates exceeding 1.

Figure 9-5 shows the results of the residential risk evaluation for lead in soil for the RYSR exposure areas, and the numeric comparisons with EPA and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10. Of the 384 exposure areas evaluated as RYSR properties, the lead EPC (represented as the UCL) exceeds the EPA RSL of 400 mg/kg at 28 exposure areas (Figure 9-5), and exceeds the provisional screening level of 140 mg/kg at 90 exposure areas. Using the mean soil lead concentrations, the EPA RSL of 400 mg/kg is exceeded at 12 exposure areas, and the provisional screening level of 140 mg/kg is exceeded at 50 exposure areas.

RSAR Properties – Figure 9-3 shows the results of the incremental residential ELCR estimates for the RSAR exposure areas. The numeric incremental ELCR estimates are provided in Table 9-6. Of the nine exposure areas evaluated as RSAR properties, the only exposure area where the incremental ELCR estimate exceeds the EPA target risk range of 1×10^{-6} to 1×10^{-4} is at the hot spot identified within Parcel Group D, which has an ELCR of 3×10^{-4} (resulting from arsenic in the berm tailings at that location). The ELCR for the remainder of Parcel Group D (excluding the hot spot) is at or below the background ELCR. The incremental ELCR estimates are within the EPA target risk range of 1×10^{-6} to 1×10^{-4} at Parcel Group A and Parcel Group H, and below 1×10^{-6} at the remaining exposure areas.

The residential HI estimates for the RSAR exposure areas for the combined child/adult exposure scenario are provided in Table 9-6. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the nine exposure areas evaluated as RSAR properties, the HI estimates exceed the EPA HI threshold value of 1 at two exposure areas (the hot spot identified within Parcel Group D, and Parcel Group F). These two exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Both of these exposure areas also have incremental HI estimates exceeding 1 (Table 9-6). These two exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-9 provides the HI results for the two exposure areas evaluated for target organ/system HI segregation. The target organ/system-specific HI estimates for both exposure areas are below the EPA HI threshold value of 1.

Figure 9-4 shows the results of the residential HI estimates for the RSAR exposure areas.

Figure 9-5 shows the results of the residential risk evaluation for lead in soil for the RSAR exposure areas. The numeric comparisons with EPA and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10. Of the 9 exposure areas evaluated as RSAR properties, the lead EPC (represented as the UCL) exceeds the EPA RSL of 400 mg/kg and the provisional screening level of 140 mg/kg only at the hot spot identified within Parcel Group D (Figure 9-5). Using the mean soil lead concentration, this same hot spot still exceeds both screening levels.

Non-Residential/Possible Future Residential Properties – Figure 9-3 shows the results of the incremental residential ELCR estimates for the exposure areas designated as Non-Residential/Possible Future Residential properties. The numeric incremental ELCR estimates are provided in Table 9-7. None of the 4 exposure areas evaluated as this property type have incremental ELCR estimates exceeding the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4}, but all are within or at the high end of this range. The incremental ELCR is almost entirely contributed by arsenic for all exposure areas.

The residential HI estimates for the Non-Residential/Possible Future Residential exposure areas for the combined child/adult exposure scenario are provided in Table 9-7. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the four exposure areas evaluated as Non-Residential/Possible Future Residential properties, the HI estimates exceed the EPA HI threshold value of 1 at two exposure areas (NR19 North of MTP and NR20 North of Chaparral Gulch). These exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Neither of these exposure areas have incremental HI estimates exceeding 1 (Table 9-7). Therefore, the target organ/system HI segregation evaluation is not conducted.

Figure 9-4 shows the results of the residential HI estimates for the RSAR exposure areas.

Figure 9-5 shows the results of the residential risk evaluation for lead in soil for the Non-Residential/ Possible Future Residential exposure areas. The numeric comparisons with EPA and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10. Of the 4 exposure areas evaluated as this property type, the lead EPC (represented as the UCL) exceeds the EPA RSL of 400 mg/kg at exposure area NR19 North of MTP only (Figure 9-5), and exceeds the provisional screening level of 140 mg/kg at 3 exposure areas. Using the mean soil lead concentrations, the EPA RSL of 400 mg/kg is not exceeded, but the provisional screening level of 140 mg/kg is exceeded at three exposure areas.

Non-Residential Properties – Figure 9-3 shows the results of the incremental residential ELCR estimates for the exposure areas designated as Non-Residential properties. The numeric incremental ELCR estimates are provided in Table 9-8. Of the 16 exposure areas evaluated as Non-Residential properties, the incremental ELCR estimates are above the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} at 12 exposure areas; they are at the high end of this range at one exposure area, and below 1 x 10^{-6} at three exposure areas. The incremental ELCR estimates for these exposure areas are almost entirely contributed by arsenic, however, there are also substantial contributions from 2,3,7,8-TCDD TEQ and carcinogenic PAHs at exposure area NR11 (former Pyrometallurgical Operations area).

The residential HI estimates for the Non-Residential exposure areas for the combined child/adult exposure scenario are provided in Table 9-8. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the 16 exposure areas evaluated as Non-Residential properties, the HI estimates exceed the EPA HI threshold value of 1 at 14 exposure areas. These 14 exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of these 14 exposure areas, the incremental HI estimates exceed the EPA HI threshold value of 1 at 13 exposure areas (Table 9-8). These 13 exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-9 provides the HI results for the 13 exposure areas evaluated for target organ/system HI segregation. Of these 13 exposure areas, the target organ/system-specific HI estimates exceed the EPA HI threshold value of 1 at 12 exposure areas. The target organ/system-specific HIs are almost entirely contributed by elevated levels of arsenic, with the exception of NR6 (Middle Chaparral Gulch), which was driven by elevated levels of manganese. There are also substantial contributions from 2,3,7,8-TCDD TEQ at NR11 (former Pyrometallurgical Operations area) and NR12 (Smelter Plateau), and elevated levels of thallium at NR14 (south of former Iron King Mine property).

All 12 of the exposure areas with target organ/system-specific HI estimates exceeding 1 also have an estimated ELCR exceeding 10^{-4} and/or a lead EPC over the EPA residential screening level of 400 mg/kg.

Figure 9-4 shows the results of the residential HI estimates for the Non-Residential exposure areas, depicting those with target organ/system-specific HI estimates exceeding 1.

Figure 9-5 shows the results of the residential risk evaluation for lead in soil for the Non-Residential exposure areas. The numeric comparisons with EPA and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10. Of the 16 exposure areas evaluated as this property type, the lead EPC (represented as the UCL) exceeds the EPA RSL of 400 mg/kg at 12 exposure areas (Figure 9-5), and exceeds the provisional screening level of 140 mg/kg at 13 exposure areas. Using the mean soil lead concentrations, the EPA residential screening level of 400 mg/kg is also exceeded at 12 exposure areas, and the provisional screening level of 140 mg/kg is exceeded at 13 exposure areas.

Residential Exposure to Ambient Air

The HI and ELCR estimates for residential exposure to ambient air are summarized for each individual monitoring station that was sampled in 2008 and 2009 during the RI. Given that the predominant wind direction is from the south-southwest, the stations have been divided into the following two groups:

- Site Downwind Stations – AES-01, AHS-02, AHS-03, AIK-01A, AIK-01, AIK-02, and AIK-03
- Background Upwind Stations – ABG-01 and AHS-01

The ambient air monitoring station locations are shown on Figure 4-6 and descriptions of the locations are provided in Table 4-1. The individual samples included for each station are listed in Appendix K1, Tables K1-5. The EPCs are provided in Appendix K3, Tables K3-5.

The results of the residential ambient air ELCR estimates are provided in Table 9-11. The ELCR estimates are within, but do not exceed, the EPA target risk range of 1×10^{-6} to 1×10^{-4} at all 7 downwind stations, and at both upwind stations. The ELCR is highest at the Stations AIK-01A (ELCR = 5×10^{-5}) and AIK-01 (ELCR = 5×10^{-5}) located within the Iron King Mine area. Arsenic contributes over 90 percent of the ELCR for these two stations. The highest ELCR for the upwind stations is 2×10^{-5} at ABG-01, also primarily from arsenic (94 percent contribution).

The numeric incremental HI estimates are also provided in Table 9-11. Of the 7 downwind stations evaluated, the HI estimates exceed the EPA HI threshold value of 1 at stations AIK-01A (HI = 2) and AIK-01 (HI = 2). These two stations have individual HQs exceeding 1 as a result of arsenic (89 percent contribution at AIK-01A; 72 percent contribution at AIK-01). The highest HI for the upwind stations is 3 at AHS-01, primarily from aluminum (90 percent contribution).

To evaluate the potential for adverse health effects from lead in ambient air, the EPCs are compared with the primary NAAQS for lead (EPA, 2008c). Based on this comparison, none of the 7 downwind stations and none of the 2 upwind stations have EPCs exceeding the NAAQS of 0.15 $\mu g/m^3$. The highest EPC is 0.045 $\mu g/m^3$, from station AIK-01 within the Iron King Mine area.

These results indicate that the highest risks and hazards from ambient air are in the immediate vicinity of the Iron King Mine and Humboldt Smelter, which have higher concentrations of arsenic than the upwind stations or any of the four in-town monitoring stations (for example, near the Humboldt Elementary School).

The uncertainties associated with the ambient air evaluation are discussed in Section 9.8.1. It should be noted that the EPCs used for this ambient air risk evaluation are considered health-conservative, because they are based on results from TSP samples. However, only air particles that are 10 micrometers in diameter or smaller (PM_{10}) are considered inhalable, because particles of such a size generally pass through the throat and nose and enter the lungs. The RI data indicate that, in general, PM_{10} levels are considerably lower than measured TSP levels.

Qualitative Evaluation of Residential Exposure to Homegrown Produce

Ingestion of homegrown produce was evaluated qualitatively for the residential exposure scenario because risks associated with direct contact with soil contribute more significantly to cumulative risk estimates.

Urban gardens have been assessed extensively since the 1970s and provide the foundation for evaluating metals in garden soil. The degree to which plants absorb various metals/metalloids from soil is related to the physicochemical properties of the chemical, the soil properties (pH, metal/metalloid concentration in soil, organic matter, cation exchange capacity, and levels of co-occurring metals/ metalloids in soil), and/or plant properties (plant age, species, type of crop, edible portion [leafy, root, or garden fruit]).

All plants contain some small amounts of arsenic (Kabata-Pendias and Pendais, 2001). Edible portions of plants seldom accumulate high concentrations of arsenic; however, both mushrooms and rice can have high levels (Walch et al., 1977; Byrne and Tusek-Znidaric, 1983; Signes-Pastor et al., 2008). Most backyard vegetable plants are sensitive to arsenic in soil and will either be killed or severely stunted long before the arsenic concentrations in the vegetables reach concentrations that pose a health risk (Walch et al., 1977; Chaney et al., 1984). Plants vary in the amount of arsenic they absorb from the soil and in which portions of the plant they store the arsenic. Fruit-bearing plants (for example, tomatoes) tend to concentrate arsenic in the roots, with very little concentration in the aboveground, edible portions (Woolson, 1973; Burlo et al., 1999). Leafy vegetables also store arsenic in the roots, but they also store some in the stems and leaves. Lettuce and other green leafy vegetables, such as collards, kale, mustard, and turnip greens, tend to store arsenic more in the leaves (Cobb et al., 2000). Root crops, such as beets, turnips, carrots, and potatoes, absorb most of the arsenic in the skin surface. Therefore, by peeling the skins of the root crops, one can eliminate the portion of the plant that contains arsenic (Helgesen and Larsen, 1998; Munoz et al., 2002).

In the Dewy-Humboldt community, greenhouse and home garden studies have demonstrated that the soil arsenic concentration and the family to which a garden plant belongs can influence the uptake of arsenic into the edible tissues of plants grown in mining-affected soils (Ramirez-Andreotta et al., 2013). These results support other findings that the lettuce, radish, kale, broccoli, and cabbage families concentrate arsenic the most (Cobb et al., 2000).

9.6.5.2 Occupational Worker Exposure Scenario

Current or future occupational workers at or near the Site are evaluated for potential exposure to COPCs detected in soil (0 to 2 feet bgs). The incremental cancer and noncancer risk estimates are described in the following subsections.

Occupational Worker Exposure to Soil

The following tables include the HI and ELCR estimates for occupational worker exposure to soil, summarized by exposure area for two current property types:

- Table 9-12 – Non-Residential/Possible Future Residential
- Table 9-13 – Non-Residential

The individual sample locations included for each exposure area are shown on Section 7 figures, and listed in Appendix K1, Tables K1-3 through K1-4. EPCs are provided in Appendix K3, Tables K3-3 through K3-4.

Non-Residential/Possible Future Residential Properties – Figure 9-6 shows the results of the occupational worker incremental ELCR estimates for the exposure areas designated as Non-Residential/ Possible Future Residential properties. The numeric incremental ELCR estimates are provided in Table 9-12. None of the four exposure areas evaluated as this property type have incremental ELCR estimates exceeding the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4}, but all are within this range. The incremental ELCR is almost entirely contributed by arsenic for all exposure areas.

The occupational worker HI estimates for the Non-Residential/Possible Future Residential exposure areas are provided in Table 9-12. None of the four exposure areas evaluated as this property type have an HI estimate exceeding the EPA HI threshold value of 1. Therefore, the incremental hazard and target organ/system HI segregation evaluations are not conducted. Figure 9-7 shows the results of the occupational worker HI estimates for the Non-Residential/Possible Future Residential exposure areas.

Figure 9-8 shows the results of the occupational worker risk evaluation for lead in soil for the Non-Residential/Possible Future Residential exposure areas. The numeric comparisons with the EPA industrial screening level (800 mg/kg) are provided in Table 9-10. None of the four exposure areas evaluated as this property type have a lead EPC that exceeds the EPA industrial screening level of 800 mg/kg.

Non-Residential Properties – Figure 9-6 shows the results of the occupational worker incremental ELCR estimates for the exposure areas designated as Non-Residential properties. The numeric incremental ELCR estimates are provided in Table 9-13. Of the 16 exposure areas evaluated as Non-Residential properties, the incremental ELCR estimates are above the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} at 4 exposure areas, within the target risk range at nine exposure areas, and below 1 x 10^{-6} at 3 exposure areas. The incremental ELCR estimates for these exposure areas are almost entirely contributed by arsenic, however, there are also substantial contributions from 2,3,7,8-TCDD TEQ and carcinogenic PAHs at exposure area NR11 (former Pyrometallurgical Operations area).

The occupational worker HI estimates for the Non-Residential exposure areas are provided in Table 9-13. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the 16 exposure areas evaluated as Non-Residential properties, the HI estimates exceed the EPA HI threshold value of 1 at 5 exposure areas. These five exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of these five exposure areas, the incremental HI estimates exceed the EPA HI threshold value of 1 at four of them (Table 9-13). These four exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-14 provides the HI results for the four exposure areas evaluated for target organ/system HI segregation. Of these four exposure areas, the target organ/system-specific HI estimates exceed the EPA HI threshold value of 1 at two of them. The target organ/system-specific HIs are almost entirely contributed by elevated levels of arsenic. There are also substantial contributions from 2,3,7,8-TCDD TEQ at NR11 (former Pyrometallurgical Operations area).

  All 4 of the exposure areas with target organ/system-specific HI estimates exceeding 1 also have an estimated ELCR exceeding 10^{-4} and/or a lead EPC over the EPA industrial screening level of 800 mg/kg.

Figure 9-7 shows the results of the occupational worker HI estimates for the Non-Residential exposure areas, depicting those with target organ/system-specific HI estimates exceeding 1.

Figure 9-8 shows the results of the occupational worker risk evaluation for lead in soil for the Non-Residential exposure areas. The numeric comparisons with the EPA industrial screening level (800 mg/kg) are provided in Table 9-10. Of the 16 exposure areas evaluated as this property type, the lead EPC (represented as the UCL) exceeds the EPA industrial screening level of 800 mg/kg at 11 exposure areas. Using the mean soil lead concentrations, the screening level is exceeded at six exposure areas.

9.6.5.3 Recreational Visitor Exposure Scenario

Current or future recreational visitors at or near the Site are evaluated for potential exposure to COPCs detected in soil (0 to 2 feet bgs), Agua Fria River sediment (0 to 0.5 foot bss), and Agua Fria River surface water. The incremental cancer and noncancer risk estimates for each of these media are described in the following subsections.

Recreational Exposure to Soil

The following tables include the HI and ELCR estimates for recreational exposure to soil, summarized by exposure area for two current property types:

- Table 9-15 – Non-Residential/Possible Future Residential
- Table 9-16 – Non-Residential

The individual sample locations included for each exposure area are shown on figures in Section 7, and listed in Appendix K1, Tables K1-3 through K1-4. EPCs are provided in Appendix K3, Tables K3-3 through K3-4.

Non-Residential/Possible Future Residential Properties – Figure 9-9 shows the results of the recreational visitor incremental ELCR estimates for the exposure areas designated as Non-Residential/Possible Future Residential properties. The numeric incremental ELCR estimates are provided in Table 9-15. None of the four exposure areas evaluated as this property type have incremental ELCR estimates exceeding the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4}, but all are within or at the low end of this range. The incremental ELCR is almost entirely contributed by arsenic for all exposure areas.

The recreational visitor HI estimates for the Non-Residential/Possible Future Residential exposure areas are provided in Table 9-15. None of the four exposure areas evaluated as this property type have an HI estimate exceeding the EPA HI threshold value of 1. Therefore, the incremental hazard and target organ/system HI segregation evaluations are not conducted. Figure 9-10 shows the results of the recreational visitor HI estimates for the Non-Residential/Possible Future Residential exposure areas.

To assess potential exposure to lead in soil for the recreational visitor exposure scenario, soil EPCs for Non-Residential/Possible Future Residential exposure areas were conservatively compared with residential screening levels. Figure 9-5 shows the results of the residential risk evaluation for lead in soil for the Non-Residential/Possible Future Residential exposure areas. The numeric comparisons with the EPA residential and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10.

Non-Residential Properties – Figure 9-9 shows the results of the recreational visitor, incremental ELCR estimates for the exposure areas designated as Non-Residential properties, and the numeric incremental ELCR estimates are provided in Table 9-16. None of the 16 exposure areas evaluated as this property type have incremental ELCR estimates exceeding the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4}, but 13 exposure areas are within this range, and 3 exposure areas have incremental ELCR estimates below 1 x 10^{-6}. The incremental ELCR estimates for these exposure areas are almost entirely contributed by arsenic, however, there are also substantial contributions from 2,3,7,8-TCDD TEQ at exposure area NR11 (former Pyrometallurgical Operations area).

The recreational visitor HI estimates for the Non-Residential exposure areas are provided in Table 9-16. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the 16 exposure areas evaluated as Non-Residential properties, the HI estimates exceed the EPA HI threshold value of 1 only at exposure area NR17 (MTP). This exposure area is further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Exposure area NR17 (MTP) also has an incremental HI estimate exceeding 1 (Table 9-16). This two exposure area is further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-14 provides the HI results for the exposure area evaluated for target organ/system HI segregation. The target organ/system-specific HI estimates for exposure area NR17 (MTP) does not exceed the EPA HI threshold value of 1.

Figure 9-10 shows the results of the recreational visitor HI estimates for the Non-Residential exposure areas.

To assess potential exposure to lead in soil for the recreational visitor exposure scenario, soil EPCs for Non-Residential exposure areas were conservatively compared with residential screening levels. Figure 9-5 shows the results of the residential risk evaluation for lead in soil for the Non-Residential/ Possible Future Residential exposure areas. The numeric comparisons with the EPA residential and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10.

Recreational Visitor Exposure to Agua Fria River Sediment

Table 9-17 provides the results of the recreational visitor ELCR and HI estimates for potential exposure to sediment within the Agua Fria River. The individual sample locations included for each of the three sediment exposure area are shown on Figure 9-2. Samples included in the HHRA are listed in Appendix K1, Table K1-6. EPCs are provided in Appendix K3, Tables K3-6.

The ELCR estimates are at the lower end of the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} for exposure areas AF-02 (adjacent to the smelter) and AF-03 (downstream of the smelter), and below the EPA target risk range for exposure area AF-01 (upstream of the smelter). The ELCR estimates for exposure areas AF-02 and AF-03 are almost entirely contributed by arsenic. The HI estimates for all three exposure areas are below the EPA HI threshold value of 1.

To assess potential exposure to lead in sediment for the recreational visitor exposure scenario, sediment EPCs were conservatively compared with residential screening levels. The numeric comparisons with the EPA residential and provisional screening levels (400 mg/kg and 140 mg/kg) are provided in Table 9-10. None of the lead EPCs (represented as the UCL) exceed the EPA residential screening level of 400 mg/kg; however, the EPCs at exposure areas AF-02 (adjacent to the smelter) and AF-03 (downstream of the smelter) exceed the provisional screening level of 140 mg/kg. None of the sediment exposure areas have mean lead concentrations that exceed either the EPA residential screening level of 400 mg/kg or the provisional screening level of 140 mg/kg.

Recreational Visitor Exposure to Agua Fria River Surface Water

Table 9-18 provides the results of the recreational visitor ELCR and HI estimates for potential exposure to surface water within the Agua Fria River. The individual sample locations included for each of the three surface water exposure area are shown on Figure 9-2. Samples included in the HHRA are listed in Appendix K1, Table K1-7. EPCs are provided in Appendix K3, Table K3-7.

The ELCR estimates are below the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} for all exposure areas. The HI estimates for all three exposure areas are below the EPA HI threshold value of 1.

To assess potential exposure to lead in surface water for the recreational visitor exposure scenario, surface water EPCs (represented by the mean) are conservatively compared with the EPA action level for lead in tap water[7] of 15 µg/L. The lead EPCs at exposure areas AF-01 (maximum of 1.1 µg/L, upstream of the smelter) and AF-02 (13.6 µg/L, adjacent to the smelter) are below the EPA action level, but the EPC at exposure area AF-03 (33.9 µg/L, downstream of the smelter) exceeds the EPA action level. However, the EPC for exposure area AF-03 is heavily weighted by inclusion of data from samples SWD-06a and SWD-06b, which were collected in August 4 and 15, 2014, immediately following storm events. These samples were intended to assess infrequent, high rainfall events; the results are considered less likely to represent the longer-term exposure conditions consistent with the human health exposure assumptions. If results from these two samples are excluded from the data set, the mean concentration from the remaining 12 sampling results in this exposure area is 1.9 µg/L, well below the EPA action level.

9.7 Summary of Baseline Human Health Risk Assessment Results

This HHRA is conducted in accordance with EPA guidance, which is summarized in Section 9.2. Risks are estimated for the most plausible pathways of human exposure, based on available sampling data and a current understanding of reasonably anticipated land uses and beneficial water uses at the Site. The exposure scenarios evaluated include:

- Current or future residents
- Current or future occupational workers
- Intermittent recreational visitors (for example, hikers)

9.7.1 Results by Medium

The HHRA results for these three exposure scenarios are summarized in Tables 9-5 through 9-18, and indicate specifics for soil, ambient air, sediment, and surface water, as described in the following subsections.

9.7.1.1 Soil

Tables 9-19 through 9-21 list those exposure areas where risk estimates exceed EPA risk thresholds (as defined in Section 9.6) for potential exposure to soil for the residential, occupational worker, or recreational visitor exposure scenarios.

The incremental residential ELCR estimates for soil exceed the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} and/or the incremental HIs exceed the EPA threshold value of 1 at numerous exposure areas that either are currently designated as residential properties, have the potential for becoming residential properties, or are expected to remain non-residential (see Figures 9-3 and 9-4). Also, numerous properties have lead concentrations exceeding residential risk-based action levels (see Figure 9-5). None of the exposure areas designated for residential screening (RSAR properties) appears to have incremental risks or hazards above EPA risk thresholds, with the exception of the stormwater diversion berm that is identified as a hot spot within exposure area RSAR-D. Outside of this hot spot, the RSAR properties do not require further evaluation.

The incremental occupational worker ELCR estimates for soil exceed the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4} and/or the incremental HIs exceed the EPA threshold value of 1 at 4 of the 20 exposure areas that are currently not residential properties (see Figures 9-6 and 9-7). In addition, 11 of these 20 exposure areas have lead concentrations exceeding the industrial screening level (see Figure 9-8).

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[7] The Agua Fria River is not considered a drinking water source.

The incremental recreational visitor ELCR estimates for soil do not exceed the EPA target risk range of 1×10^{-6} to 1×10^{-4} and the incremental HIs do not exceed the EPA threshold value of 1 at any of the 20 exposure areas that are currently not residential properties (see Figures 9-9 and 9-10). However, 13 of these 20 exposure areas have lead concentrations exceeding the residential screening level (see Figure 9-5).

9.7.1.2 Ambient Air

The residential ELCR estimates for ambient air do not exceed the EPA target risk range of 1×10^{-6} to 1×10^{-4} at all 7 downwind monitoring stations, and at both upwind stations. Of the 7 downwind monitoring stations, the HI estimates slightly exceed the EPA HI threshold value of 1 at Stations AIK-01A (HI = 2) and AIK-01 (HI = 2). These results indicate that the highest risks and hazards from ambient air are in the immediate vicinity of the Iron King Mine and Humboldt Smelter, which have higher concentrations of arsenic than the upwind stations or any of the four in-town monitoring stations (for example, near the Humboldt Elementary School). Also, none of the 7 downwind stations or 2 upwind stations detected lead levels in dust exceeding the NAAQS of 0.15 $\mu g/m^3$. Therefore, no unacceptable residential health risks are identified for any of the ambient air monitoring stations near current residential areas.

9.7.1.3 Agua Fria River Sediment and Surface Water

The recreational visitor ELCR estimates for sediment and surface water do not exceed the EPA target risk range of 1×10^{-6} to 1×10^{-4} and the HIs do not exceed the EPA threshold value of 1 at any of the exposure areas evaluated. Also, average lead concentrations do not exceed risk-based screening levels. Therefore, no unacceptable recreational visitor health risks are identified for these exposure areas.

9.7.2 Chemicals of Concern

Under CERCLA guidance, those COPCs identified during the baseline risk assessment as primary risk contributors should be retained as COCs for further evaluation of remedial options during the FS stage of the RI/FS. Given that the risks and hazards estimated in this HHRA exceed CERCLA's acceptable risk thresholds for soil at the Site, COCs are identified for each exposure area where risk is identified, based on the primary risk/hazard contributors listed in Tables 9-19 through 9-21. The primary COCs based on the HHRA are arsenic and/or lead that originate from mine- and smelter-related activities; however, some localized areas include other risk drivers (for example, 2,3,7,8-TCDD TEQ and carcinogenic PAHs at exposure area NR11 [former Pyrometallurgical Operations area]). The presence of risk levels that exceed EPA risk thresholds indicates that evaluation of actions to address human exposure pathways is necessary for the forthcoming FS for the Site. Section 10 evaluates ecological risks separately to identify chemicals of ecological concern.

9.8 Uncertainties Associated with this Baseline HHRA

The presence of uncertainty is inherent in the risk assessment process. Estimates of risk should present not only point estimates, but also account for the sources and magnitude of uncertainty associated with these estimates, provide characterizations of risk that are both qualitative and quantitative, consider the limits of scientific knowledge, and identify when there is a possibility of either overestimation or underestimation. Sources of uncertainty in risk assessment range from the assumptions and methodologies used in the evaluation of exposures and risks, to data gaps in the qualitative and quantitative information used to characterize the cancer and noncancer risks posed by site contaminants.

Several sources of uncertainty can affect the overall estimates of human health risks presented in this assessment. The sources are generally associated with the following:

- Sampling, analysis, and data evaluation
- Chemical fate and transport estimation
- Exposure assessment
- Toxicity assessment
- Risk characterization

These sources of uncertainty are discussed in the following sections.

9.8.1 Sampling, Analysis, and Data Evaluation

Uncertainties associated with soil, ambient air, sediment, and surface water sampling and analysis include the inherent variability (standard error) in the analysis, the representativeness of the samples, sampling errors, and the heterogeneity of the sample matrix. The quality assurance and quality control programs used during site investigations are intended to maintain acceptable precision and accuracy in the measurement of chemical concentrations, but they cannot eliminate all errors associated with sampling and analysis. The degree to which sample collection and analyses reflect real exposure concentrations will influence the reliability of the risk estimates. The RI data included in this HHRA are considered of suitable quality for assessing risk, and adequate for reliable risk management decisions for the Site.

Because of the sources and history of releases at the Site, the RI media sampling strategies have been both judgmental and systematic across the Site. Judgmental samples were collected, in some cases, at locations where contamination would be most expected, such as, at visible fill and roadbed application of mine and smelter soil and/or waste rock/tailings. Inclusion of these data into the HHRA could result in potential overestimation of exposure, contributing to some uncertainty in the risk estimates. For other areas (other than mine and smelter soil and waste rock/tailings), the sampling approach was generally more systematic (for example, in specific residential yards) and as a result, the areal average concentrations are more reliable and uncertainties associated with exposure are lower.

It should be noted that the EPCs used for the ambient air risk evaluation are considered health-conservative, because they are based on results from TSP samples. The sizes of dust particles are directly linked to their potential for causing health problems. EPA is most concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose, and enter the lungs. The RI data indicate that in general, PM_{10} levels are considerably lower than measured TSP levels, more so when high wind (and higher TSP) conditions exist. EPCs based on the inhalable fraction (PM_{10}) would, therefore, be expected to be lower than when using TSP; and exposures and risks would be proportionately lower.

The use of XRF data for soil metals/metalloids for this HHRA introduces some uncertainty into the risk estimates. However, as described in Section 6.1, correlation and regression analyses were used to compare XRF and laboratory data and develop adjustment equations for application to measured XRF data to make them correspond to expected laboratory results. This adjustment was designed to account for inherent differences between the two methods. It was performed to generate a consistent dataset, while allowing for substantially greater geographic coverage and density of the analytical results. Given the strength in the correlations between the XRF and laboratory data for arsenic, iron, lead, manganese, and zinc, adjusted data for these metals are considered sufficiently reliable for risk management decisions.

9.8.2 Chemical Fate and Transport Estimation

This HHRA assumes that no chemical loss or transformation has occurred since the sampling data were collected, or will occur over the course of the assessed exposure durations. In cases for which natural attenuation or other degradation processes are moderate or high, the analytical data chosen to represent exposure concentrations likely overstate actual long-term exposure levels. This uncertainty is likely to be more relevant for organic chemicals (such as PAHs), which can be expected to undergo some limited biodegradation over the assumed 26-year residential exposure duration, than for those that are more environmentally stable (such as metals).

9.8.3 Exposure Assessment

The estimation of exposures in this HHRA requires many assumptions. There are uncertainties regarding the likelihood of exposure, frequency of contact with contaminated media, EPCs, intake rates, and total duration of exposure. When site-specific information is lacking, the exposure assumptions in this HHRA (Table 9-2) are selected to reduce the likelihood of underestimating actual risks, and are thereby intended to be health protective. For example, the assumed exposure frequency of 52 days per year for the recreational visitor exposure scenario is based on the health-protective assumption that a 10-year-old adolescent would swim in the Agua Fria River for one hour, one day per week year-round.

To provide for more reliable exposure estimates for chromium in soil and ambient dust, the RI includes specific analytical methods to speciate this metal. The results allow for site-specific adjustment to exposures, rather than assuming, by default, that all chromium in these media was in the most toxic hexavalent form. The analyses reveal that no hexavalent chromium was detected in soil. Therefore, chromium is assumed to be present predominantly in the less toxic trivalent form.

Another uncertainty for the risk assessment is the bioavailability of the forms of metals that occur in site media at the site. The HHRA conservatively assumes that bioavailability from soil/sediment is the same as that in the toxicological studies from which the toxicity values were derived. One exception is arsenic, where a site-specific bioavailability adjustment factor was estimated (see Appendix H) using test results from 72 soil samples collected across the site from a combination of residential and non-residential areas (gulch areas, Humboldt Smelter area, and MTP). For the remaining metals, depending on whether the chemical form at the site is less or more bioavailable than assumed, actual risk would be proportionately lower or higher, respectively.

9.8.4 Toxicity Assessment

Uncertainties in toxicological data can also influence the reliability of risk management decisions. The toxicity values used for quantifying risk in this HHRA have varying levels of confidence, which may affect the confidence in the resulting risk estimates. The general sources of toxicological uncertainty include the following:

- Extrapolation of dose-response data derived from high-dose exposures to adverse health effects, which may occur at the low levels seen in the environment
- Extrapolation of dose-response data derived from short-term tests to predict effects of chronic exposures
- Extrapolation of dose-response data derived from animal studies to predict effects on humans
- Extrapolation of dose-response data from homogeneous populations used in laboratory studies to predict effects on heterogeneous human populations

The levels of uncertainty associated with the RfDs and RfCs for the COPCs (as judged by EPA) are expressed as uncertainty factors and modifying factors; these are provided in IRIS or other sources (discussed in Section 9.5.3). For chemicals suspected of resulting in cancer effects, uncertainty is, in part, expressed in terms of the EPA weight-of-evidence classification. More specific areas of toxicological uncertainty associated with this HHRA are as follows:

- There is some uncertainty associated with the oral RfD for arsenic of 0.0003 mg/kg-day used for this HHRA. The IRIS summary profile for arsenic (EPA, 2016) indicates that, currently, there is not a clear consensus among EPA scientists on the oral RfD. Applying EPA's RfD methodology, strong scientific arguments can be made for various values within a factor of 2 or 3 of the currently recommended RfD values. For example, an RfD ranging from 0.0001 to 0.0008 mg/kg-day is considered plausible. It should be noted, however, that the RfD methodology, by definition, yields a number with inherent uncertainty, spanning perhaps an order of magnitude. Risk management decisions based on a noncancer endpoint from exposure to arsenic should recognize the considerable flexibility afforded when these uncertainties and lack of clear consensus are taken into account.
- The HHRA used available chronic RfDs and RfCs. The use of chronic values may be conservative for some receptors at the site (for example child-only noncancer estimates), because it is most likely that any exposure would be of a shorter-than-lifetime duration.
- Toxicity values were not available from the sources listed in Section 9.5.3, for some chemicals detected; therefore, a surrogate toxicity factor for a structurally similar chemical was used.[8] Inclusion of these surrogates in the HHRA may result in an overestimation of risk at the site, if, in fact, a site chemical is less toxic than its assigned surrogate. Most of the toxicological literature focuses on the chemicals considered more toxic to human receptors. Site contamination was derived from sources associated with historical facility operations. Toxicity values for chemicals associated with these sources are readily available; and chemicals without toxicity values do not represent a significant uncertainty in this HHRA.
- Dermal exposures are different from oral exposures because: 1) not all of a chemical that comes into contact with a person's skin travels across the various layers of epidermal tissue, as indicated by a skin permeability factor; and 2) the toxic effects produced from this route of exposure may not be the same as when the chemical is ingested. In lieu of available toxicity values for the dermal route, this HHRA uses oral toxicity values to estimate the effects of dermally available chemicals. This approach may result in underestimating or an overestimating risks, depending on whether a chemical is more or less toxic by the dermal route versus by ingestion.
- The toxicity values available from EPA and other sources are intentionally health protective so that actual risks are unlikely to be underestimated. For example, cancer slope factors are typically based on the 95 percent UCL of the slope of the dose-response curve.

9.8.5 Risk Characterization

In the risk characterization for the Site, the assumption was made that the total risk of developing cancer from exposure to site chemicals is the sum of the risk attributed to each individual contaminant. Likewise, the potential for the development of noncancer, adverse health effects is the sum of the HQs estimated for exposure to each individual contaminant. This approach, in accordance with EPA guidance, does not account for the possibility that some chemicals may act synergistically or antagonistically. In the absence of specific information about the interaction, the default assumption of additivity is considered appropriate.

To assess potential risks for lead in soil, lead concentrations are compared to both the current RSLs and the provisional screening level in this HHRA to provide the range of potential for adverse effects from lead exposure, and allow for the most informed risk management decisions for the site. It should be noted that the provisional screening value has not been fully promulgated by EPA and is currently under

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[8] The surrogate toxicity factors selected for the risk assessment are listed in the last column of Table 9-3.

review. As such, this value is not intended for general application at this time. The application of further regulatory developments related to risk assessment for lead exposure at the Site will be revisited during the 5-year review process.

EPA guidance indicates that the arithmetic mean should be used as the concentration term when modeling blood-lead levels in children and adults (EPA, 2015b, 2015c). For this HHRA, both the mean and 95 percent UCL concentrations of lead in soil for each exposure area are compared to these risk-based screening levels. Where a UCL is used, the result could be interpreted as a more health-conservative estimate of the risk of an elevated blood-lead level.

Because some chemicals that are detected in environmental media occur naturally, or are found regionally as a result of general anthropogenic sources, when interpreting cancer and noncancer risk estimates, it is important to consider the relative level of potential risk posed by these naturally and anthropogenic occurring levels. To allow for greater clarity and transparency in the risk characterization for the site, background samples for soil from outside the APSI were collected during the RI, and cancer and noncancer risks from exposure to naturally occurring levels of metals are estimated and reported herein for comparison, in accordance with EPA guidance (EPA, 2002b). In addition, incremental risks are estimated using the approach described in Section 9.6.4.

9.8.5.1 Child-only Noncancer Hazard Estimates

For evaluations of noncancer effects, both combined child/adult and child-only scenarios are considered in this HHRA. As previously discussed, the child-only scenario is a more health-conservative evaluation that is included to provide EPA with added input for determining borderline decisions for remediating specific properties at the Site. This section provides the results and conclusions for the child-only scenario. Given the uncertainties inherent in the RfD for arsenic (ranging up to about threefold), and the uncertainties associated with applying chronic RfDs to shorter duration exposures, a child-only noncancer HI estimate of 3 or higher is considered in this site-specific uncertainty analysis to provide a meaningful indication of the potential for risk. The results of the site-specific uncertainty analysis are provided in the following subsections.

RYSR Properties

The residential HI estimates for the RYSR exposure areas for the child-only exposure scenario are provided in Table 9-5. The noncancer HI results, using the tiered approach described in Section 9.6.2.1, are summarized as follows:

- **Step 1** – Of the 384 exposure areas evaluated as RYSR properties, the child-only HI estimates are above 1 at 373 exposure areas. These 373 exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of these 373 exposure areas, 74 exposure areas have incremental HI estimates exceeding 1 (Table 9-5). These 74 exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-22 provides the HI results for the 74 exposure areas evaluated for target organ/system HI segregation. Of these 74 exposure areas, 17 exposure areas have target organ/system-specific HI estimates of 3 or higher.

  Of these 17 exposure areas with target organ/system-specific HI estimates of 3 or higher, 11 exposure areas also have estimated ELCR exceeding 10^{-4} and/or a lead EPC over the EPA residential screening level of 400 mg/kg.

  Of the remaining six exposure areas, two (exposure areas 2328 and 2426) are driven by elevated levels of arsenic, three (exposure areas 1907, 1910, and 1911) are driven by elevated levels of manganese and iron, and one (exposure area 45066) is driven by elevated levels of thallium.

However, the elevated levels of metals present in soil at exposure areas 1907, 1910, 1911, and 45066 do not appear to be from mine- or smelter-related sources; these are further evaluated in Section 7.1.

RSAR Properties

The residential HI estimates for the RSAR exposure areas for the child-only exposure scenario are provided in Table 9-6. The noncancer HI results are summarized as follows:

- **Step 1** – Of the nine exposure areas evaluated as RSAR properties, the child-only HI estimates exceed 1 at all nine exposure areas. These nine exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of the nine exposure areas, two exposure areas have incremental HI estimates exceeding 1 (Table 9-6). These two exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-22 provides the HI results for the two exposure areas evaluated for target organ/system HI segregation. Both exposure areas (the hot spot identified within Parcel Group D and Parcel Group F) have estimated target organ/system-specific HI estimates of 3 or higher.

  Of the two exposure areas with target organ/system-specific HI estimates of 3 or higher, the hot spot identified within Parcel Group D also has an estimated ELCR exceeding 10^{-4} and a lead EPC over the EPA residential screening level of 400 mg/kg.

  The target organ/system-specific HI for Parcel Group F is driven by elevated levels of manganese. However, the elevated levels of manganese present in soil at Parcel Group F do not appear to be from mine- or smelter-related sources; these are further evaluated in Section 7.

Non-Residential/Possible Future Residential Properties

The residential HI estimates for the Non-Residential/Possible Future Residential exposure areas for the child-only exposure scenario are provided in Table 9-7. The noncancer HI results are summarized as follows:

- **Step 1** – The child-only HI estimates exceed 1 at all four exposure areas evaluated as Non-Residential/Possible Future Residential properties. These four exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of these four exposure areas, two exposure areas (NR19 North of MTP and NR20 North of Chaparral Gulch) have incremental HI estimates exceeding 1 (Table 9-7). These two exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-22 provides the HI results for the two exposure areas evaluated for target organ/system HI segregation. Both exposure areas have target organ/system-specific HI estimates exceeding 3. The target organ/system-specific HIs are driven by elevated levels of arsenic at exposure area NR19 North of MTP, and by elevated levels of manganese at exposure area NR20 North of Chaparral Gulch.

  Exposure area NR19 North of MTP also has an estimated ELCR exceeding 10^{-4} and a lead EPC over the EPA residential screening level of 400 mg/kg.

  The elevated levels of manganese present in soil at exposure area NR20 North of Chaparral Gulch do not appear to be from mine- or smelter-related sources; these are further evaluated in Sections 7 and 8.5.

Non-Residential Properties

The residential HI estimates for the Non-Residential exposure areas for the child-only exposure scenario are provided in Table 9-8. The noncancer HI results are summarized as follows:

- **Step 1** – Of the 16 exposure areas evaluated as Non-Residential properties, the child-only HI estimates exceed 1 at all 16 exposure areas. These 16 exposure areas are further evaluated in Step 2 to estimate incremental HI.
- **Step 2** – Of these 16 exposure areas, 14 exposure areas have incremental HI estimates exceeding 1 (Table 9-8). These 14 exposure areas are further evaluated in Step 3 to conduct target organ/system HI segregation.
- **Step 3** – Table 9-22 provides the HI results for the 14 exposure areas evaluated for target organ/system HI segregation. Of these 14 exposure areas, 12 exposure areas have target organ/system-specific HI estimates of 3 or higher.

  All of these 12 exposure areas with target organ/system-specific HI estimates of 3 or higher, also have an estimated ELCR exceeding 10^{-4} and a lead EPC over the EPA residential screening level of 400 mg/kg.

The overall results of the site-specific uncertainty analysis indicate that the RYSR properties at exposure areas 2328 and 2426 exhibit sufficiently high child-only HI estimates to justify inclusion of these exposure areas for evaluation in the forthcoming FS for the Site. This additional weight-of-evidence was considered to include these exposure areas because they have both a cancer risk at the high end of the EPA risk management range (10^{-6} to 10^{-4}) and a child-only HI exceeding 3 for a mine-related metal (arsenic).

Baseline Ecological Risk Assessment

10.1 Introduction

This section provides a description of and the results of the ERA performed for the Iron King Mine – Humboldt Smelter Superfund Site. The ERA represents an analysis of potential adverse effects (current or future) to ecological receptors from chemical substances released from the Site in the absence of any actions to control or mitigate those releases. The ERA identifies and characterizes the toxicity of the chemicals of potential ecological concern (COPECs), the potential exposure pathways, the potential ecological receptors, and the likelihood of adverse ecological effects under current and reasonably anticipated future land and water use conditions.

10.1.1 Objectives and Scope

The overall objectives of this ERA are to quantitatively and qualitatively evaluate baseline or existing exposure and risks to ecological receptors (other than domesticated species), and to provide risk managers with information needed to achieve their ecological management goals and help determine remedial decisions, if necessary.

The scope of this ERA includes the following:

- Identifying habitats, ecological receptors, and COPECs
- Selecting assessment endpoints and measures
- Characterizing potential ecological exposures
- Selecting appropriate ecological benchmarks and toxicity reference values (TRVs)
- Evaluating potential ecological risks to determine chemicals of ecological concern (COECs)

10.1.2 Guidance

This ERA was performed in general accordance with EPA guidance listed below:

- *The Role of Screening-Level Risk Assessments and Refining Contaminants of Concern in Baseline Ecological Risk Assessments* (EPA, 2001)
- *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* (EPA, 1999)
- *Guidelines for Ecological Risk Assessment* (EPA, 1998)
- *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments, Interim Final* (EPA, 1997a)
- *ProUCL Version 5.0.00 Technical Guide, Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations* (EPA, 2013c)

10.1.3 Approach

The ERA followed the eight-step approach recommended by EPA (EPA, 1997a) and shown on Figure 10-1. These steps can be grouped into three main phases as follows:

Screening-Level Ecological Risk Assessment (SLERA): The SLERA represents Steps 1 and 2 of Superfund guidance (EPA, 1997a). The SLERA intentionally uses conservative assumptions to screen the initial list of detected constituents to identify those constituents requiring further evaluation. The principal components of the SLERA are the screening level problem formulation (Step 1), exposure estimation, effects evaluation, and screening-level risk calculation (Step 2). COPECs identified for further evaluation are carried forth to the baseline ecological risk assessment (BERA).

Baseline Ecological Risk Assessment (BERA): The BERA consists of several steps designed to refine exposure and risk estimates in a scientifically defensible manner. Refinements include use of less conservative exposure and toxicity assumptions in the risk calculations (Step 3). These refined calculations can lead to a decision to conduct additional studies to further refine exposure estimates and effects relationships (Steps 4 through 6) or, through completion of the risk characterization (Step 7), serve as the BERA for the Site.

Risk Management: The final step (Step 8) utilizes the results of the BERA to assist in risk management decisions.

EPA recognizes that the eight-step approach is not a linear or sequential process and some steps may not be necessary to reach a decision point. Throughout the ERA process, the risk assessment review team and risk managers evaluate available information for use in planning future needs/direction of the ERA. This communication between the ecological risk review team and the risk managers is termed the Scientific Management Decision Point (SMDP). It is an integral part of the ERA process.

10.1.4 Assumptions

The ERA was conducted under the following assumptions and constraints, which are typical for ERAs performed under CERCLA:

- All evaluation of current exposures is derived from existing conditions.
- Future land use is assumed to remain the same as current use.
- The abiotic media of primary ecological concern include soil, sediment, and surface water.
- Biotic media utilized in exposure and risk modeling includes upland vegetation.
- Current chemical concentrations are assumed to be at steady state levels and will not change over time.
- Chemicals not detected or analyzed are not present or evaluated.
- Each chemical is as bioavailable as the chemical on which the toxicity information is based when used for estimating direct exposure to chemicals in soil, sediment, or surface water.
- Where site-specific tissue data are not available, bioaccumulation of chemicals is estimated using bioaccumulation factors, bioconcentration factors, or regression modeling.
- Toxicological information used represents information currently available from literature and database searches.
- Home ranges of representative receptors were considered for wildlife exposures in the BERA evaluation.

10.1.5 Organization

The ERA is organized as follows:

Section 10.1 Introduction – Provides the objectives and scope, guidance, approach, and assumptions used in the ERA.

Section 10.2 SLERA – Provides the SLERA problem formulation (ecological setting, selection of representative endpoint species, assessment endpoints and measures, and ecological conceptual site model), exposure and effects evaluation (data evaluation and identification of screening levels), risk calculations, and SMDP 1.

Section 10.3 BERA – Provides the BERA problem formulation, analysis (exposure characterization and ecological effects characterization), and risk characterization (risk estimation, risk description, and uncertainty analysis), and SMDP 2.

10.2 Screening-Level Ecological Risk Assessment

The SLERA provides the screening level problem formulation (Step 1), exposure estimation, effects evaluation, and screening-level risk calculation (Step 2) of the EPA risk assessment process. The product of the SLERA is a list of COPECs in soil, sediment, and surface water that are recommended for further evaluation in the BERA.

10.2.1 SLERA Problem Formulation

The SLERA problem formulation provides and overview of the Site and establishes the goals, scope, and focus of the ERA.

10.2.1.1 Ecological Setting

The operational site history is presented in Section 2. The physical setting is presented in Section 5, with the ecological setting described in Section 5.6. The general habitats found at the Site are shown on Figure 5-14. Plant and wildlife species observed at the Site during the course of the surveys conducted by EnviroSystems Management (2009) and Lockheed Martin SERAS (2015) are summarized in Table 10-1 and special-status species that may potentially occur in Yavapai County, Arizona are summarized in Table 10-2.

10.2.1.2 Ecological Conceptual Site Model

The preliminary CSM for chemical fate and transport at the Site was described in Section 8, including the current understanding of historical and ongoing sources, release mechanisms, and contaminant transport and environmental fate processes. The ecological conceptual site model combines information on potential ecological receptors (Section 5.6 and Table 10-1), potential sources of contaminants, and potential exposure pathways to provide an overall picture of site-related exposures, and to focus the evaluation of chemical constituents in the ERA. Figure 10-2 presents the ecological conceptual site model for ecological exposure pathways at the Site.

Exposure Pathway Analysis

Exposure pathways refer to the media and routes through which inorganic and organic constituents can reach ecological receptors. Potential exposure pathways must meet specific criteria for an exposure to occur. Aside from necessary habitat for ecological receptors, a complete exposure pathway must include the following elements:

- Source (for example tailings)
- Mechanism for release and transport (such as surface runoff or leaching)
- Exposure point (for example sediment)
- Feasible route of exposure (such as ingestion)
- Receptors (such as birds or mammals)

Potentially complete ecological exposure pathways at the Site include the following:

- Potential exposure of soil invertebrates and terrestrial plants to site-related constituents present in soil
- Potential exposure of terrestrial wildlife (birds and mammals) through ingestion of site-related constituents in soil, terrestrial forage, and/or prey items

- Potential exposure of aquatic and benthic resources (aquatic plants, benthic and water column invertebrates, and fish) to site-related constituents present in sediment or surface water
- Potential exposure of semi-aquatic wildlife (birds and mammals) through ingestion of site-related constituents in sediment, aquatic forage/prey, and surface water

Selection of Representative Endpoint Species

To evaluate ecological exposure, representative endpoint species are selected for the functional feeding guilds that may have potentially complete exposure pathways. Consistent with *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments, Interim Final* (EPA, 1997a), these endpoint species should preferably be ones that have ecological relevance, are of societal value, are susceptible to chemical stressors at the Site, and allow risk managers to meet policy goals. These factors are used to select representative endpoint species common to the Site or adjacent habitats. The representative species selected for each feeding guild and habitat type are as follows:

- Terrestrial Exposures
  - Terrestrial vegetation (evaluated as a group)
  - Soil invertebrates (evaluated as a group)
  - Herbivorous birds – Gambel’s quail (*Callipepla gambelii*)
  - Insectivorous birds – Western kingbird (*Tyrannus verticalis*)
  - Omnivorous birds – song sparrow (*Melospiza melodia*)
  - Carnivorous birds – red-tailed hawk (*Buteo jamaicensis*)
  - Herbivorous mammals – pocket gopher (*Peromyscus leucopus*)
  - Insectivorous mammals – desert shrew (*Nitiosorex crawfordii*)
  - Omnivorous mammals – raccoon (*Procyon lotor*)
  - Carnivorous mammals – coyote (*Canis latrans*)
- Semi-aquatic/Aquatic Exposures
  - Aquatic/wetland vegetation (evaluated as a group)
  - Aquatic organisms- water column invertebrates, amphibians, and fish (evaluated as a group)
  - Benthic organisms – benthic macroinvertebrates (evaluated as a group)
  - Omnivorous birds – mallard (*Anas platyrhynchos*)
  - Piscivorous birds – great blue heron (*Ardea herodias*)
  - Omnivorous mammals – raccoon (*Procyon lotor*)
  - Piscivorous mammals – river otter (*Lutra Canadensis*)

Brief species profiles for the selected representative species are provided below. Specific representative species were not selected for plant, invertebrate, or fish functional groups. Rather, each functional group was evaluated as a whole.

Vegetation

Vegetation is a primary producer and can include upland, wetland, and aquatic plants, which may be rooted or free-floating. Common plants that may be present include grasses, rushes, sedges, forbs, and algae. Vegetation is a vital part of the food chain, serving as a main food source for both herbivorous and omnivorous species. Terrestrial and wetland plants are in direct contact with potentially contaminated soil and/or sediment. They are non-mobile and have high exposure to chemical stressors. Plants may also bioaccumulate chemical stressors in the leaves and other aboveground structures. They serve as a food source for birds and mammals.

Invertebrates

Invertebrates are primary consumers and include upland species (earthworms and insects), benthic species (those living in the sediment), or water-column species (such as daphnia). Invertebrates primarily serve as food sources for fish and omnivorous and insectivorous birds and mammals. Soil and sediment-dwelling invertebrates are in direct contact with potentially contaminated soil and/or sediment. Water-column invertebrates are primarily exposed to contaminants in surface waters. Invertebrates typically have a relatively small range, high reproductive rates, and serve an integral role in the ecosystem.

Fish

Fish are secondary or tertiary consumers and may be exposed to contaminants in surface water and prey items. They are forage for higher tropic-level fish, birds, and mammals. Fish may be exposed to chemicals in sediment or surface water through ingestion, dermal contact, and uptake through gills, and by feeding on contaminated plants, aquatic invertebrates, or smaller fish.

Herbivores

Gambel’s quail (*Callipepla gambelii*) is an easily identified bird common in the Sonoran desert (Gee et al., 2013). They are residents throughout southern Arizona and feed primarily on forbs, grasses, shrubs, trees, and cacti. They may consume a small percentage of insects in the summer; however, they are evaluated as herbivores in this assessment. Nest sites are predominantly on the ground concealed under a shrub or in a protected site. Peak hatching occurs in May. Both parents lead chicks to food by pecking and tid-bitting the ground. Habitat quality is the primary factor determining the bird’s abundance at any given time.

The pocket gopher (*Peromyscus leucopus*) is identified as a representative receptor species for evaluation of the potential for adverse effects to herbivorous mammals. The pocket gopher is an appropriate receptor species because it is common to chaparral habitats, consumes a wide variety of plant material, and is a potential food source for other animals. Given their life history and feeding habits, gophers are expected to provide a precautionary representative model of exposures for other chaparral partially or predominantly herbivorous mammals, including mice, rats, gophers, and prairie dogs.

Insectivores

The western kingbird (*Tyrannus verticalis*) is commonly spotted in a variety of habitats including riparian forests, savannahs, shrublands, pasture and cropland, deserts, and urban areas (Gamble and Bergin, 2012). The western kingbird fees on insects, primarily foraging in the air, but also gleaning insects from vegetation. The western kingbird defends a small territory around its nest against potential predators. It will nest in a variety of natural and human-made structures.

The desert shrew *(Nitiosorex crawfordii)* is identified as a representative receptor species for evaluation of the potential for adverse effects to insectivorous mammals. Desert shrews consume a diet composed almost entirely of insects, and are a potential food source for other animals. Given their life history, feeding habits, and high ingestion rates, shrews are expected to be precautionary representative of other chaparral partially or predominantly carnivorous mammals, including skunks, mice, and bats. In addition, sufficient data is available for this species to support quantitative evaluation of food web exposures.

Omnivores

The song sparrow (*Melospiza melodia*) is one of the most diverse and widespread songbirds in North America (Arcese et al., 2002). They are identified as a representative receptor species for evaluation of the potential for adverse effects to upland omnivorous birds. During the nonbreeding period, they feed primarily on seeds, fruits, and invertebrates. During the breeding season, they feed primarily on insects and other small invertebrates. In winter, the song sparrows are an appropriate representative receptor because they are expected to be present at the Site, consume primarily seeds and insects, and have similar life history and feeding habits to that of many other common birds.

Mallards (*Anas platyrhynchos*) are omnivorous, surface-feeding ducks that are widespread throughout most of the United States. They are identified as a representative species for the evaluation of semi-aquatic omnivorous birds. They are the most abundant of all ducks. Mallards forage in ponds and wetlands, feeding on aquatic plants, seeds, and aquatic invertebrates by dabbling and filtering through sediments. Wintering mallards prefer natural bottomland wetlands and rivers. Nesting habitats are generally dense with grassy vegetation at least a half-meter high. Mallards prefer areas that provide concealment from predators, such as seeded cover, cool-season-introduced legumes and grasses, and idle grassland with tall, dense rank cover in the area (EPA, 1993b).

Raccoons (*Procyon lotor*) are the most widespread and abundant medium-sized omnivore in North America. They are found in virtually all aquatic habitats, particularly in hardwood swamps, mangroves, floodplain forests, and freshwater and saltwater marshes. They are common in both suburban and rural areas. Raccoons are omnivorous and are evaluated under both terrestrial and semi-aquatic exposure models. They are very opportunistic with a diet made up primarily of fleshy fruits, nuts, acorns, and corn, but they also eat grains, insects, frogs, crayfish, eggs, and virtually any animal and vegetable matter. Diet is highly varied depending on location and season, although plants are usually a more important component of the diet. Mating season ranges from January through June, depending on location, and females produce only one litter a year (EPA, 1993b).

Carnivores

The red-tailed hawk (*Buteo jamaicensis*) is identified as a representative receptor species for evaluation of the potential for adverse effects to predatory birds. Hawks are an appropriate representative receptor because they are expected to be present at the Site, consume a diet composed of primarily of small mammals and birds, and have a life history and feeding habits similar to that of other predatory birds. They are expected to provide a precautionary representative model of exposures for other chaparral birds of prey including other hawks, owls, and eagles.

The coyote (*Canis latrans*) is identified as a representative receptor species for evaluation of the potential for adverse effects to predatory mammals. Coyotes consume a diet composed primarily of small mammals, birds, and carrion. Given their life history and broad range of prey consumed, coyotes are expected to be precautionary representative of other chaparral predators such as fox. In addition, sufficient data is available for this species to support quantitative evaluation of food web exposures.

Piscivores

Species that consume primarily fish, called piscivores, may potentially be present at the Site in association with riparian corridor habitats. These species consume fish and other aquatic organisms such as crustaceans or amphibians. Piscivores may be exposed to chemicals at the Site through ingestion of chemicals in sediment, surface water, and prey. Given the limited amount of persistent aquatic habitat present at the Site, the number of primarily piscivorous species present at the Site is expected to be extremely limited. The most likely exposure scenario linking piscivores to site exposures is occasional or period foraging by highly mobile receptors.

The great blue heron (*Ardea herodias*) is identified as a representative receptor species for evaluation of the potential for adverse effects to piscivorous birds. Herons are an appropriate representative receptor because they could periodically utilize the surface water features at the Site and consume a diet composed of primarily of fish and aquatic organisms. They are expected to provide a precautionary representative model of exposures for other chaparral wildlife that consume prey from aquatic habitats.

The northern river otter (*Lutra Canadensis*) historically lived in or near lakes, marshes, streams, and seashores (EPA, 1993b). Coastal populations are stable, but the species is extirpated in much of the

Midwestern United States. The river otter was selected as a representative piscivore because historically, it may have been present near the Site utilizing the Agua Fria River. The bulk of their diet is fish, but they are opportunistic, so will feed on a variety of prey depending on availability. The river otter's home range encompasses the area needed for foraging and reproduction.

10.2.1.3 Assessment Endpoints and Measures

The conclusion of the screening level problem formulation is the identification of assessment and measurement endpoints. Superfund guidance states that assessment endpoints are any adverse effects on ecological receptors, where receptors are populations and communities, habitats, and sensitive environments (EPA, 1997a). The assessment endpoints for the Site are any adverse effects on receptor populations and communities for non-threatened-and-endangered species. Adverse effects on these assessment endpoints are predicted from measurement endpoints. The measurement endpoints for this site are the effects of chemical exposure on reproduction, survival, or growth, which can be used to predict effects at all levels of organization (individual, population, and community); these factors are considered in the identification and evaluation of appropriate toxicity information.

Assessment endpoints frequently cannot be directly measured because they tend to correspond to complex ecosystem attributes. Because of this, the ERA identifies other related measures that serve as representations or surrogates of each assessment endpoint. These measures are called "measures of effect" and "measures of exposure" (EPA, 1998). The strength of the relationships between these measures and their corresponding assessment endpoints is critical to the identification of ecological adversity. For this ERA, these measures are defined as follows:

- Measures of exposure are quantitative or qualitative indicators of a constituent's occurrence and movement in the environment in a way that results in contact with the assessment endpoint. For example, chemical concentrations detected in surface soil serve as a measure of exposure to terrestrial wildlife that could use habitats potentially impacted by the Iron King Mine and Humboldt Smelter.
- Measures of effect are measurable adverse changes in an attribute of an assessment endpoint (or its surrogate) in response to a chemical to which it is exposed. For example, literature-derived toxicity reference values from available laboratory studies on birds are used to indicate when birds may be adversely affected.

Based on the information gathered during previous investigations and for this RI, the assessment endpoints identified for the Site and the corresponding measures of exposure and effect are summarized in Table 10-3.

10.2.2 SLERA Exposure Assessment and Risk Calculation

The SLERA-level exposure and risk calculation is the final step in the SLERA. Data are evaluated for usability in the ERA and exposure areas are identified based on the results of the ecological conceptual site model (Figure 10-2). A roadmap summarizing the ecological exposure areas, available data, and exposure pathways being evaluated is presented in Table 10-4.

Background threshold values (BTVs) and ecological screening values (ESVs) are identified for each medium and receptor group, and a conservative risk calculation is completed. Chemicals that show a potential for risk to generalized receptor groups are identified as COPECs and are carried forth to the BERA. Chemicals that do not indicate a potential for risk are eliminated from further evaluation.

10.2.2.1 Exposure Assessment

Exposure Areas

Exposure areas are those geographic areas over which investigation data are aggregated for computation of UCLs, and where independent estimates of risk are quantified. Implicit in the exposure area concept is the assumption that the receptor has equal likelihood of exposure to contamination at any individual location within the identified exposure area. Due to the large geographic scale of the Site and the possibility that some receptor types could be exposed over smaller areas, the Site was partitioned into numerous exposure areas. Exposure areas in the residential areas were identified primarily for evaluation in the HHRA and were not evaluated for potential risks to ecological receptors. The exposure areas surrounding the residential areas and along the Agua Fria River were identified as the primary points of exposure for ecological receptors. The ecological exposure areas are shown on Figure 10-3.

Data Evaluation

Analytical data from the following investigations at the Iron King Mine – Humboldt Smelter Superfund Site were used in this ERA:

- 2002 PA/SI of the Former Iron King Mine (ADEQ, 2002)
- 2004 PA/SI of the Former Humboldt Smelter (ADEQ, 2004)
- 2005 EPA Removal Assessment (E & E, 2005)
- 2008 Ironite Products Company/NAI Sampling (Brown and Caldwell, 2009b)
- 2008 to 2009 Initial RI (EA, 2010)
- 2010 Supplemental RI (EA, 2011)
- 2012 to 2013 Background and Surface Soil Sampling (EPA, 2012b)
- 2013 to 2014 Data Gap RI (Lockheed Martin SERAS, 2015)

These pre-NPL and RI investigations are described in Sections 3 and 4. The methodology used to compile these data, and the data reduction procedures, are outlined in Section 6.1, Data Usability and Processing. The RI data from these investigations and included in this ERA were determined to be of suitable quality for assessing ecological risk, and adequate for reliable risk management decisions for the Site.

The ERA used analytical data collected from the following environmental media:

- Soil (from 0 to 2 feet bgs) – sampling locations used in the ERA are shown on Figure 10-4.
- Agua Fria River sediment (from 0 to 0.5 feet bgs – sampling locations used in the ERA are shown on Figure 10-5.
- Agua Fria River surface water – sampling locations used in the ERA are shown on Figure 10-6.

Data reduction included resolution of native and field duplicate pairs and reduction of analytes reported under multiple methods. The following data reduction rules were applied to identify data for use in the ERA:

- Chemical results with final validation qualifiers of any letter(s) other than those containing a “U,” “UJ,” or “R” were considered detected.
- Estimated values (flagged with “J” qualifiers) were treated as detected concentrations.
- Chemical results with final validation qualifiers containing an “R” were considered rejected data and were removed from the database.
- Data for chemicals considered essential for nutrition were excluded from evaluation: calcium, magnesium, potassium, sodium.

- For duplicate samples, the following procedure was applied:
  - If there were two detections, the higher of the two concentrations was used.
  - If there was one detection and one nondetection, the detected value was used.
  - If there were two nondetections, the lowest detection limit was used.

Soil metals and metalloids data used for this ERA include results from both certified laboratory analyses and samples analyzed in the field by portable XRF spectroscopy. Sampling protocols for XRF analysis included the periodic collection of paired samples for laboratory analysis. As described in Section 6.2, linear regression analyses were performed on the paired samples to determine whether the XRF data reliably correspond to measured laboratory data. Correlation and regression analyses were used to compare XRF and laboratory data for arsenic, chromium, copper, iron, lead, manganese, and zinc, and to develop adjustment equations for application to measured XRF data to make them correspond to expected laboratory results. These adjusted data were subsequently incorporated into the Site database. The ERA only uses the adjusted XRF data when corresponding laboratory results at that location are not available.

Chemical data meeting the data evaluation requirements were retained for further evaluation in the ERA. Statistical evaluations of the chemicals detected in each medium were performed and included the following:

- Number of detects
- Number of nondetects
- Percent detection
- Minimum and maximum nondetected values
- Minimum and maximum detected values
- Mean of detects
- Median of detects
- Standard deviation of detects
- Exposure point concentration (NOTE: the EPC values are not utilized until the BERA and their derivation is discussed in further detail in that section).

The results of the statistical evaluations for the Site are provided in Appendix M (supplemental ERA information) as follows:

- Table M-1 – Soil
- Table M-2 – Sediment
- Table M-3 – Surface water

10.2.2.2 Background Threshold Values

BTVs were developed for several metals detected in surface soil. The derivation process is described in Section 6.2 and Appendix E (Soil Background Study Report), and is summarized here. Summary statistics were calculated using the best result from shallow soil samples (sample beginning depth of 0 feet bgs), collected between 2002 and 2013, from areas outside of the defined background boundary (see Figure 6-1), both west and east of the Agua Fria River. The 95/95 UTLs were used to define background in surface soil, as these estimates are designed to be greater than 95 percent of the values in the background population with a confidence of 95 percent. This is a conservative approach, because it allows up to 5 percent of soil samples with concentrations of target metals equivalent to the upper tail of background values to exceed the BTV and be considered “above background.”

BTVs are presented in Appendix M, Table M-4 and are used along with ecological screening values (described below) in the identification of COPECs.

10.2.2.3 Screening Values

The SLERA uses conservative ESVs selected from widely accepted sources. Screening levels are typically based on a no-effect level and are protective of ecological receptors exposed to that medium. In general, a top tier source was selected first, followed by the most conservative between second tier sources.

Soil Screening Values

Soil ESVs were identified for two larger receptor groupings: 1) plants and invertebrates, and 2) birds and mammals. Grouping of receptors provides the most conservative evaluation of potential risks because ESVs are not available for all receptor and chemical pairs. Soil ESVs, which are summarized in Appendix M, Table M-4, were obtained from the following sources:

- Terrestrial plants and invertebrates
  - EPA ecological soil screening levels (EcoSSLs; EPA, various years) – more conservative value between plants and invertebrates selected first, followed by the most conservative between Los Alamos National Laboratory (LANL) and Canadian Council of Ministers of the Environment (CCME):
    - LANL soil screening benchmarks - more conservative value between plants and invertebrates (LANL, 2014)
    - CCME soil screening values for agricultural use (CCME, 2011)
- Birds and mammals
  - EPA EcoSSLs (EPA, various years) - more conservative value between birds and mammals followed by:
    - LANL soil screening benchmarks - more conservative value between birds and mammals (LANL, 2014)
    - EPA Region 5 ecological screening levels for soil (EPA, 2003a)

Sediment Screening Values

Sediment ESVs selected are considered generally protective for most benthic receptors that reside in sediment, including benthic microorganisms and benthic macroinvertebrates. Sediment ESVs are summarized in Appendix M, Table M-5 and were obtained from the following sources:

- Freshwater threshold effect concentrations (MacDonald et al., 2000)
- EPA Region 3 marine sediment screening benchmarks (EPA Region 3, 2006a)
- National Oceanic and Atmospheric Administration freshwater sediment benchmarks (lowest levels) for infauna (Buchman, 2008)
- USDI low effect level of selenium (USDI, 1998)

Surface Water Screening Values

Surface water ESVs are generally protective for most aquatic receptors that reside in the water column including aquatic plants, water-column invertebrates, amphibians, and fish. Surface water ESVs, which are summarized in Appendix M, Table M-6, were obtained from the following sources:

- National Recommended Water Quality Criteria (NRWQC) - chronic exposure (EPA, 2009d)
- Arizona Water Quality Standards for Surface Waters (ADEQ, 2009)
- Tier II chronic screening values (Suter and Tsao, 1996)

Water quality criteria are based on dissolved concentrations for arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. In addition, criteria for each of these metals, with the exception of arsenic and mercury, are also hardness dependent. The dissolved, hardness-dependent criteria for these metals were derived using the conversion equations provided by EPA (EPA, 2009d) and the average hardness for sampling locations in the Agua Fria River (297 mg/L $CaCO_3$) as follows:

$$\text{CCC (dissolved)} = \exp(m_C\,[\ln\{\text{hardness}\}] + b_C) \times (\text{CF})$$

Where:

CCC = criterion continuous concentration (chronic)
CF = conversion factor

And:

Analyte	m_C	b_C	CF
cadmium	0.7409	-4.719	1.101672[ln(hardness) × 0.041838]
chromium III	0.819	0.6848	0.86
copper	0.8545	-1.702	0.96
lead	1.273	-4.705	1.46203[ln(hardness) × 0.145712]
nickel	0.846	0.0584	0.997
silver (CMC)	1.72	-6.59	0.85
Zinc	0.8473	0.884	0.986

10.2.2.4 Screening Risk Calculation

The SLERA risk calculation is a conservative estimation of the potential for risk to ecological receptors. All detected chemicals in each exposure area and medium were evaluated in the SLERA risk calculation. Metals considered consistent with background were not excluded from the SLERA.

The screening-level HQs were calculated using the following equation:

$$Screening\ HQ = \frac{Maximum\ detected\ concentration\ (mg/kg\ or\ \ mg/L)}{ESV\ (mg/kg\ or\ \ mg/L)}$$

10.2.2.5 Identification of Chemicals of Potential Ecological Concern

COPECs were identified from the results of the background comparisons (soil only) and screening risk calculations as follows:

- Chemicals with maximum detected concentrations below BTVs (where available) were not considered to pose a risk to ecological receptors and were not selected as COPECs.
- Chemicals with maximum detected concentrations exceeding BTVs (where available) were retained or excluded as COPECs based on the results of the screening risk calculations as follows:
  - Chemicals with screening HQs greater than or equal to 1 or for which ESVs were not available were identified as COPECs and were carried forward to BERA.
  - Chemicals with screening HQs less than 1 were not considered to pose an unacceptable risk to ecological receptors and were eliminated from further evaluation.

The SLERA risk calculation and identification of COPECs for each exposure area and receptor grouping are provided in Appendix M, Tables M-7 (soil), M-8 (sediment), and M-9 (surface water). A summary of COPECs for each exposure area and medium is presented in Table 10-5.

10.2.3 SMDP 1

The SLERA indicated that there is a potential for adverse risk to ecological receptors from chemicals detected in soil, sediment, and/or surface water from several of the exposure areas within the Site. The chemicals detected in Cs for each exposure area and media, detected chemicals, and identification of COPECs in each medium and exposure area recommended for further evaluation in the BERA.

10.3 Baseline Ecological Risk Assessment

The BERA consists of several steps designed to refine exposure and risk estimates in a scientifically defensible manner. The BERA for the Site includes a refined problem formulation (Step 3), analysis (Step 6), and risk characterization (Step 7). SMDP 2 is the result of the BERA and summarizes conclusions and recommendations for the Site based on ecological concerns.

10.3.1 BERA Problem Formulation

The Problem Formulation provided in the SLERA (Section 10.2.1) applies to both the SLERA and BERA portions of this ERA. Additional exposure, toxicity, and risk evaluation refinements that are utilized in the BERA to further focus the risk assessment are summarized below and discussed in the following subsections:

- EPCs are determined using statistical evaluations where sufficient data are available.
- Receptor-specific exposure parameters are utilized in the food-chain uptake model to provide estimates of exposure that are more realistic.
- Site collected biological tissues (vegetation) are used to provide more realistic estimate of uptake into forage plants ingested by birds and mammals.
- Both low and high ecological benchmarks and TRVs are used, where available, to provide a range of risk estimates for each receptor group.
- Risk estimates are completed on a receptor (or functional group)-specific basis to provide information on exposure pathways that may be driving risk and to provide a more realistic estimate of the overall potential for risk to ecological populations using the Site.
- A weight-of-evidence approach is utilized to weigh potential risks and provide a defensible rationale for the determination of COECs that may be recommended for further evaluation in the forthcoming FS.

10.3.2 BERA Analysis

The analysis phase links the problem formulation phases (Sections 10.2.1 and 10.3.1) with the risk characterization phase (Section 10.3.3), and consists of the technical evaluation of ecological and chemical data to determine potential for ecological exposure and effects. The analysis phase includes the exposure characterization and the ecological effects characterization. These two components are used to evaluate the relationships among receptors, potential exposures, and potential effects. The results provide the information necessary to estimate potential risks to the representative species under the conditions defined for the Site.

10.3.2.1 Exposure Characterization

The exposure characterization is used to evaluate the relationship between receptors at the Site and COPECs. The methods used to refine exposure estimates, including receptor-specific exposure models, site-specific data, and calculation of EPCs, are described in the following subsections.

Exposure Models

The exposure model describes the relationships and equations used to estimate how much of a given chemical in a given medium is being taken up by the receptor through a given exposure route. These relationships can be simple or complex depending on the receptor involved and the number of exposure routes being evaluated. Both concentration-based and dosage-based models were used.

Concentration-based Exposure Model

The concentration-based model used in the BERA is the same as that used in the SLERA, whereby exposure is expressed as the concentration of each chemical in the medium to which the receptor is most likely exposed. The ecological groups for which this exposure model is used are as follows:

- Terrestrial plants (soil)
- Soil invertebrates (soil)
- Aquatic and benthic plants (sediment)
- Benthic macroinvertebrates (sediment)
- Aquatic organisms including aquatic plants, water column invertebrates, amphibians, and fish (surface water)

Dosage-based Exposure Model

The general exposure model to be used for birds and mammals is based on exposure to contaminants through multiple pathways including soil, sediment, surface water, and food items. To address these multiple pathways, a food-chain uptake model is used. Exposure estimates for each representative species are generated using the following:

- EPCs for abiotic media of concern
- Receptor-specific exposure factors (or life-history parameters)
- Bioaccumulation potential in food items
- Area use and migration factors

The product of the BERA exposure estimate is a dosage (mg/kg-day) rather than a medium concentration (as was used for the SLERA). This is a function of both the multiple pathway approach and the typical methods used in toxicity testing for birds and mammals. The following generalized exposure model is used:

$$E_j = \left(S_j \times P_s \times FIR\right) + \left(\sum_{i=1}^{N} B_{ij} \times P_i \times FIR\right) + \left(Water_i \times WIR\right) \times AUF$$

Where:

E_j = Total exposure (mg/kg-day)
S_j = Constituent concentration in soil/sediment (mg/kg)
P_s = Soil/sediment ingestion rate as a proportion of diet
FIR = Total food ingestion rate for the representative species (kg_{diet}/kg_{bw}-day)
B_{ij} = Constituent concentration (j) in biota type (i) (mg/kg)
P_i = Proportion of biota type (i) in diet
$Water_j$ = Constituent concentration in water (mg/L)
WIR = Total water ingestion rate for the representative species (L/kg_{bw}-day)
AUF = Area use factor (fraction of foraging range)

Exposure Factors. Species-specific life history factors are needed to estimate exposure to COPECs for each representative wildlife receptor. These include body weight, food ingestion rates, water ingestion rates, incidental soil or sediment ingestion rates, and diet composition. Species-specific exposure assumptions for estimating wildlife contaminant intake from site-related COPECs are presented in

Appendix M, Table M-10. Allometric equations were used to compute food ingestion and water ingestion rates normalized to the wildlife receptor's body weight, with units of kilograms of dry food per kilogram body weight per day or liters of water per kilogram body weight per day, respectively (Nagy, 2001).

Bioaccumulation into Food Items. Bioaccumulation can be defined as the uptake and accumulation of chemicals by organisms from the nonliving (abiotic) environment or through the diet. Concentrations of COPECs in forage and prey are estimated using site-specific or literature-based bioaccumulation factors (BAFs) or regression modeling. BAFs and uptake regression equations and are presented in Appendix M, Tables M-11 (soil-based uptake) and M-12 (sediment-based uptake).

Site-specific plant uptake factors were calculated from co-located soil and vegetation samples collected at random locations throughout the Site during the 2014 fieldwork conducted by Lockheed Martin SERAS (2015). Ten co-located samples were collected. Evaluation of data indicated that uptake regressions were not significant. As such, sample-specific BAFs and metal-specific median and 90th percentile BAFs were calculated (presented in Appendix M, Table M-13). The median BAF was used for estimating potential risks in the BERA.

Area Use Factors. Many wildlife species are highly mobile, covering relatively large areas in search of food, water, and shelter. As such, the exposure that individual receptors experience depends on the amount of time they spend at a contaminated site. The area use factor (AUF) is a ratio of the size of a site (or exposure area) relative to an animal's foraging range using the following equation. This value is incorporated in the exposure model to give a more realistic estimation of overall exposure.

$$AUF = \frac{Exposure\ area\ (acres)}{FRx}$$

Where:

AUF = Area Use Factor
Exposure Area = Size of exposure area (acres)
FR_x = Foraging range for target species x (acres)

AUFs were derived for each receptor/exposure area pair, as summarized in Appendix M, Table M-14. If the receptor's foraging range is less than the size of the exposure area, the AUF defaulted to 1.

Exposure Point Concentrations. EPCs were developed for each medium in each exposure area using EPA's ProUCL statistical program (EPA, 2013a) following the procedures described in Section 9.4.2. The BERA EPCs are provided in the following Appendix M, Tables M-1 (soil), M-2 (sediment), and M-3 (surface water).

Exposure Summary

Exposures for each receptor group are calculated as described below for each medium; all exposures use receptor-specific ingestion rates and diet composition fractions:

Soil-based Exposures

- Terrestrial Plants - Direct contact and/or root uptake of COPECs in soil from each exposure area for which COPECs were identified
- Soil Invertebrates - Direct contact and/or ingestion of COPECs in soil from each exposure area for which COPECs were identified

- Birds and Mammals (terrestrial exposures)
  - Incidental ingestion COPECs in soil from each exposure area for which COPECs were identified.
  - Ingestion of modeled concentrations of COPECs in terrestrial vegetation, soil invertebrates, and/or small mammals as determined by each receptor's feeding guild. Concentrations in forage and prey are modeled using soil EPCs and BAFs or regression models
  - Note: surface water ingestion is not included in the exposure for terrestrial receptors as surface water data were not available for the terrestrial exposure areas. The potential impact on risk estimates is discussed in the uncertainty section

Sediment-based Exposures

- Aquatic and Wetland Plants – Direct contact and/or root uptake of COPECs in sediment from the Agua Fria River
- Benthic Macroinvertebrates - Direct contact and/or ingestion of COPEC in sediment from the Agua Fria River
- Birds and Mammals (semi-aquatic exposures)
  - Incidental ingestion of COPECs in sediment from the Agua Fria River
  - Ingestion of modeled concentrations of COPECs in aquatic vegetation, aquatic or benthic invertebrates, and/or fish as determined by each receptors feeding guild. Concentrations in forage and prey are modeled using sediment EPCs and BAFs or regression models
  - Ingestion of COPECs in surface water from the Agua Fria River

Surface water-based Exposures

- Aquatic organisms (plants, invertebrates, and fish) – Direct contact and/or ingestion COPECs in surface water from the Agua Fria River

10.3.2.2 Ecological Effects Characterization

The ecological effects characterization consists of an evaluation of available toxicity or other effects information that can be used to relate the exposure estimates to a level of adverse effects. Stressor-response (effects) data that can be used to evaluate ecological risks resulting from chemical exposures comprise three general categories: literature-derived or site-specific single-chemical toxicity data, site-specific ambient media toxicity tests (bioassays), and site-specific field surveys (Suter et al., 2000).

Single-chemical toxicity data found in the literature were used as the primary basis for the BERA risk estimates and consist of ecological toxicity benchmarks and TRVs. Ecological benchmarks are concentrations of chemicals in media (soil, sediment, or surface water) corresponding to effects levels and are reported in mg/kg or mg/L. TRVs are dosage-based effects levels and are reported as mg/kg-day. The specific format of toxicity values for each receptor group being evaluated in this ERA is provided below along with the sources of values. Values were generally selected in a hierarchical order (sources are listed in order from highest to lowest preference). However, if two sources were considered of equivalent quality from a scientific standpoint, then the source with less conservative values was used first.

Literature-based Toxicity Benchmarks and Toxicity Reference Values

Terrestrial and Wetland Plants

Ecological toxicity benchmarks for rooted plants exposed to soil or sediment are represented as the concentration of the chemical in soil that results in an adverse effect. Ecological toxicity benchmarks used in the BERA correspond to potential for low effects including lowest observed effect concentrations (LOECs), low effect benchmarks, soil quality guidelines, and maximum acceptable toxicant concentrations (MATCs).

The ecological toxicity benchmarks for plants, provided in Appendix M, Table M-15, were selected from the following sources:

- Low effect benchmarks for plants (LANL, 2014)
- Soil quality guidelines for ecological receptors (CCME, 2011)
- Benchmarks for terrestrial plants (Efroymson et al., 1997a)
- Peer-reviewed literature

Soil Invertebrates

Ecological toxicity benchmarks for soil invertebrates exposed to COPECs in soil are represented as the concentration of the chemical in soil resulting in an adverse effect. Ecological toxicity benchmarks used in the BERA correspond to potential for low or mid-range effects including effective concentrations where 20 percent of the test population showed effects (EC_{20}), LOECs, and MATCs.

Ecological toxicity benchmarks for soil invertebrates, provided in Appendix M, Table M-16, were selected from the following sources:

- Low effect benchmarks for invertebrates (LANL, 2014)
- Soil quality guidelines for ecological receptors (CCME, 2011)
- Benchmarks for soil invertebrates (Efroymson et al., 1997b)
- Peer-reviewed literature

Birds and Mammals

TRVs for birds and mammals are typically represented as a dosage (the amount of an analyte per unit body weight per day) that results in an adverse effect. The TRVs for birds and mammals were selected using the following hierarchy of sources:

- Toxicity values provided in the EPA EcoSSLs (EPA, various dates)
- Toxicological benchmarks for Wildlife (Sample et al., 1996)
- Region 9 Navy Biological Technical Assistance Group (BTAG) bird and mammal TRVs (Cal-EPA, 2009)
- Toxicity values provided in EPAs IRIS database (EPA, 2016)
- Peer-reviewed literature

TRVs were classified into two categories: no observed adverse effect level (NOAEL)-based TRVs and lowest observed adverse effect level (LOAEL)-based TRVs. TRVs based on mid-level or acute effect levels were only used in absence of other more appropriate endpoints, and were adjusted to a NOAEL or LOAEL using uncertainty factors.

For analytes with EcoSSLs for birds and mammals, the NOAEL used to derive the final EcoSSL was used in this ERA. If this value was the highest NOAEL below the lowest LOAEL for studies evaluating growth and reproduction endpoints, then the paired LOAEL from that study was selected for the LOAEL-based TRV for this ERA. If the EcoSSL TRV was based on the geometric mean of the NOAELs for growth and reproduction endpoints, then the geometric mean of the LOAELs from the corresponding studies was used as the LOAEL-based TRV.

For analytes lacking BTAG TRVs or EcoSSLs, appropriate toxicity studies were selected based on several criteria. Specifically, toxicity studies were selected for use if exposure was chronic or during reproduction (a critical life stage), the dosing regime was sufficient to identify both a NOAEL and a LOAEL, and the study considered ecologically relevant effects (growth, reproduction, or survival).

The toxicological studies were evaluated for endpoints and assigned uncertainty factors (UFs), if necessary, to normalize the endpoints to either a NOAEL-based or LOAEL-based TRV as follows:

Endpoint	Type	To Chronic NOAEL	To Chronic LOAEL
Low BTAG TRV	Chronic	1	--
NOAEL	Chronic/Subchronic	1	--
High BTAG TRV	Chronic	5	1
LOAEL	Acute	10	5
LOAEL	Chronic/Subchronic	5	1
LD_{50}	Acute	100	10

LD_{50} – lethal dose for 50 percent of a population (or of test organisms)

An upward conversion was made to adjust the Final Chronic NOAEL TRV to a Final Chronic LOAEL TRVs in the absence of a study with a low-level endpoint (a NOAEL was available, but a LOAEL was not available). An “upward” UF of 0.2 was used; it is identical to the “downward” UF to convert a chronic LOAEL to a chronic NOAEL. Risk calculation spreadsheets are set up to divide the base TRV by any applicable UF to arrive at the final TRV; therefore, the upward UF is represented as a fraction. For example, the UF to convert from a chronic LOAEL to a chronic NOAEL is 5. If a chronic NOAEL was available, but a LOAEL (or any other toxic endpoint [such as LD_{50}]) was not available, the chronic NOAEL was divided by 0.2 (UF of 5 converted to a fraction) to estimate a chronic LOAEL. Use of an upward conversion allows for estimating a range of potential risks in the absence of High TRVs, and is scientifically defensible as long as the same UFs are used for each endpoint or exposure duration (upward or downward).

TRVs selected for birds and mammals are provided in Appendix M, Tables M-17 and M-18, respectively.

Benthic Macroinvertebrates

Ecological toxicity benchmarks for benthic macroinvertebrates exposed to sediment are represented as the concentration of the chemical in sediment that results in an adverse effect. Ecological toxicity benchmarks for benthic macroinvertebrates used in the BERA included both no-effect and low/mid-range effect concentrations.

The sediment toxicity benchmarks used, which are provided in Appendix M, Table M-19, were identified from the following sources:

- Threshold effects concentration and probable effects concentration (MacDonald et al., 2000)
- Threshold effect level and probable effects level (Buchman, 2008)
- Threshold effects concentration and probable effects concentration (Buchman, 2008)
- Low and High effect levels (USDI, 1998)
- Freshwater Sediment Screening Benchmarks (EPA, 2011c)
- Upper effect threshold (Buchman, 2008)

Aquatic Organisms

Ecological toxicity benchmarks for aquatic organisms are concentration-based values and are generally protective for most aquatic receptors that reside in the water column including aquatic plants, water-column invertebrates, and fish. Chronic toxicity benchmarks were obtained from ADEQ (2009), NRWQC (EPA, 2009d), and Suter and Tsao (1996), which were previously presented in Appendix M, Table M-6.

10.3.3 BERA Risk Characterization

The risk characterization evaluates the evidence linking exposures to COPECs with their potential ecological effects on the representative species identified for the Site. This evaluation was completed through the integration of information gathered in the SLERA and BERA problem formulation, analysis, and other lines of evidence. For this ERA, the evidence evaluated consisted of measured chemical concentrations in abiotic media (soil, sediment, and surface water), measured and modeled concentrations in biota (for food-chain uptake), exposure estimates for representative species, toxicity information obtained from the literature, quantitative risk estimates (site, incremental, and reference), and qualitative evaluations made during the biological reconnaissance survey (Lockheed Martin SERAS, 2015). The risk characterization includes three components: risk estimation, risk description, and uncertainty analysis. These three components were used together to identify the final COECs and provide supporting information for SMDP 2.

10.3.3.1 Risk Estimation

The risk estimation phase focuses primarily on quantitative methods to evaluate the potential for risk. The results of the quantitative risk estimation are represented as HQs. Risk estimates were computed for the following.

Estimated Site Risks

Estimated Site risks were developed for two types of comparisons using the following equations:

1. Direct comparisons of measured concentrations in soil, sediment, or surface water with the respective ecological toxicity benchmarks for each COPEC. These comparisons were conducted for terrestrial plants and soil invertebrates exposed to soil; benthic macroinvertebrates exposed to sediment; and aquatic organisms (water-column plants, invertebrates, and fish) exposed to surface water using the following equation:

$$HQ = \frac{EPC}{BM}$$

Where:

HQ = Ecological hazard quotient (unitless)
EPC = Exposure point concentration (mg/kg or mg/L)
BM = Ecological toxicity benchmark (mg/kg or mg/L)

2. Comparisons of estimated total exposure dosages through the food-chain uptake model with effects dosage TRVs. The food-chain uptake model for birds and mammals results in a total exposure dosage that includes ingestion of sediment/soil, surface water, and forage/prey, where forage/prey items have potentially bioaccumulated contaminants from sediment or soil. The food-chain uptake HQ calculated as follows:

$$HQ = \frac{E_j}{TRV} \times AUF$$

Where:

HQ = Ecological hazard quotient (unitless)
E_j = Total exposure (mg/kg-day)
TRV = Toxicity reference value (mg/kg-day)
AUF = Area use factor

Incremental Risk Estimates for Soil

Potential risks attributable to background levels in soil are addressed by computing incremental risks. Incremental risk is defined as that portion of the Site risk in excess of that resulting from normal regional background or ambient concentrations of metals, and presumably attributable to site-related releases. Incremental risk is calculated as follows:

$$Incremental\ HQ = Site\ HQ - Background\ HQ$$

Background HQs were calculated in the same manner as Site HQs, with the exception that the chemical-specific BTV was used as the EPC. Background HQs were only calculated for receptor/chemical pairs with Site HQs exceeding 1 for soil-based exposures. Calculation of background HQs and incremental risks for plants and invertebrates are provided alongside the Site risk calculations for each representative receptor. Background HQs for birds and mammals were calculated using the food-chain uptake model that was used for the calculation of Site HQs and are presented in Appendix M, Table M-20. Incremental risks for birds and mammals are calculated in the same tables as Site risks (presented below).

Reference Location Risk Estimates for Sediment and Surface water

Background threshold values were not available for sediment or surface water; however, several samples were collected upstream from the Site and were used to provide a reference for potential impacts from upstream sources. Most of the flow in the Agua Fria River upstream of the Site consists of effluent from the Prescott Valley Wastewater Treatment Plant, except possibly during higher flow storm events. The designated uses of surface water in the reach of the Agua Fria River near the Site are domestic water source, full-body contact (swimming), fish consumption, agricultural irrigation, agricultural livestock watering, and aquatic and wildlife (warm water) (ADEQ, 2009). The reference locations were defined as follows, as shown on Figures 10-5 (sediment sampling locations) and 10-6 (surface water-sampling locations):

Segment	Sample Locations	Description
REF-AF	BKG-AF-3, BKG-AF-4	Main channel of the Agua Fria upstream from AF-01 and other reference segments
REF-West	BKG-AF-8, BKG-AF-9, BKG-AF-10	Drainage entering the Agua Fria from the West just downstream from REF-AF and upstream of REF-East
REF-East	BKG-AF-5, BKG-AF-6, BKG-AF-7	Drainage entering the Agua Fria from the East just downstream from REF-West and upstream of AF-01

Risk Estimation Results

Estimated risks were calculated for each representative species or functional group, for all COPECs identified for each exposure area at the Iron King Mine – Humboldt Smelter Site. All HQs are rounded to one significant figure in accordance with general recommendations by EPA to provide consistency with the HHRA. A HQ that exceeds 1 indicates that there is a potential for adverse ecological effects associated with exposure to that COPEC. COPECs with HQs exceeding 1 are evaluated further in the risk description component of the BERA, where additional lines of evidence are considered. HQ values less than or equal to 1 are considered protective the receptor's feeding guild and the COPEC is eliminated from further review.

The results of the risk estimation are provided in the following Appendix M tables:

- Soil-based exposures
  - Terrestrial plants – Appendix M, Table M-21
  - Soil invertebrates – Appendix M, Table M-22
  - Birds and mammals – Appendix M, Table M-23

- Sediment-based exposures
  - Aquatic/wetland plants – Appendix M, Table M-24
  - Benthic macroinvertebrates – Site risk estimates (Appendix M, Table M-25) and reference location risk estimates (Appendix M, Table M-26)
  - Birds and mammals –Appendix M, Table M-27
- Surface water-based exposures
  - Aquatic organisms – Site risk estimates (Appendix M, Table M-28) and reference location risk estimates (Appendix M, Table M-29)

Due to the large number of computations made (33 terrestrial exposure areas with 10 representative species, 3 sediment exposure areas with 7 representative species, and 3 surface water exposure areas with 1 representative receptor group, all evaluated using multiple TRVs), results by exposure area or receptor are not individually listed or discussed. However, BERA risk estimates for soil and sediment exposure pathways are summarized in Appendix M, Table M-30 (soil exposure pathways), Appendix M, Table M-31(sediment-based exposure pathways).

All COPECs with one or more HQs exceeding 1 at the low benchmark or NOAEL-based TRV were retained for further evaluation in the risk description and weight-of-evidence evaluation below. COPECs with HQs that do not exceed one for any receptor were considered not to pose an unacceptable risk to ecological receptors and were eliminated from further evaluation.

10.3.3.2 Risk Description and Weight-of-Evidence Evaluation

Not all of the Site risk estimates with HQs exceeding 1, provided in Section 10.3.3.1, are ultimately ecologically meaningful. The risk description component of the BERA includes an evaluation of the lines of evidence supporting or refuting the risk estimates and an interpretation of the significance of the adverse effects on the identified assessment endpoints. To provide confidence in any decision making for ecological resources at the Site, potential effects to plant, aquatic, and wildlife communities are assessed using an approach that considers multiple lines of evidence collectively, in accordance with EPA guidance in *Guidelines for Ecological Risk Assessment* (EPA, 1998).

The additional lines of evidence considered include the following:

- Incremental risk estimates for metals with available soil BTVs
- Consideration of uncertainties in risk estimates for plants and invertebrates
- Consideration of soil pH when addressing potential risks from aluminum
- Consideration of estimated risks for upstream reference locations for sediment and surface water
- Consideration of localized hotpots in sediment
- Qualitative evaluations of stream health and diversity in Lockheed Martin SERAS (2015)

Consideration of Incremental Risk Estimates

Incremental risks were calculated for arsenic, for analytes with BTVs and Site HQs>1. Background concentrations account for a portion of the total estimated risks for a given receptor. However, receptors are often adapted to the local conditions. Incremental risk is the portion of total Site risk that is because of background. Potential risk in excess of background risk was used as a key identifier for a chemical to be retained as a COEC.

Consideration of Estimated Risks for Plants and Soil Invertebrates

Uncertainties in the estimated risks for plants and soil invertebrates as well as the general importance of these receptors in remedial decisions affect the usefulness of the calculated HQs. The ecological toxicity benchmarks for plants are often based on crops and may or may not also have soil pH requirements.

The ecological toxicity benchmarks for soil invertebrates are based on earthworms and their applicability to aboveground insects or arid conditions is uncertain. The toxicity benchmarks for plants and soil invertebrates have an inherent level of uncertainty, and as such, estimated risks to plants and soil invertebrates are not used as the sole determinant for the retention of a chemical as a COEC.

Consideration of Soil pH for Assessing Risks to Aluminum

The potential for ecological risks associated with aluminum in soil or sediment are identified based on the measured soil/sediment pH (EPA, 2003c). Aluminum is identified as potentially posing a risk only for soil or sediment with a pH less than 5.5, because the soluble and toxic forms of aluminum are only present under pH values of less than 5.5. The soil pH was measured for many exposure areas, but not all. Where pH data are available, the average pH for the exposure area is used to help identify COECs. For exposure areas where the soil pH was not measured, the pH levels of surrounding exposure areas or the entire Site are used to provide additional weight-of-evidence regarding potential toxicity from aluminum.

Consideration of Estimated Risk at Upstream Reference Locations

Sediment and surface waters collected from locations upstream of the Iron King Mine or the Humboldt Smelter were considered to be representative of existing loads and stresses on the Agua Fria River before the inputs from the Iron King Mine or Humboldt Smelter. Upstream sample locations were grouped into three stream sediments defined as REF-AF, REF-West, and REF-East (Figures 10-5 and 10-6). In the event that estimated risks in one of the Agua Fria ecological exposure areas (AF-01, AF-02, and AF-03) were less that those modeled for one of the upstream references, the chemical was not considered site-related.

Consideration of Localized Hot Spots

Potential risks in the Agua Fria sediments in exposure area AF-02 are driven by samples collected near the former Humboldt Smelter property source areas. For example, locations OW-20 and OW-21 have the highest concentrations of copper and are located adjacent to the slag piles in an area where dross and slag extend down to the Agua Fria River.

Consideration of SERAS Observations during Reconnaissance level Survey

Benthic macroinvertebrate samples were collected at seven sampling locations along the Agua Fria following rapid bioassessment protocols during the week of May 6, 2014 (Lockheed Martin SERAS, 2015). These were collected at AGBIO-01, AGIO-04, AGBIO-06, AGBIO-08, AGBIO-09, and AGBIO-11. A diverse benthic community was found at all of the locations examined. No real differences in the benthic community, species or general abundance of organisms was observed between the upstream and downstream of the Site. Although the stream was somewhat compromised (for example, by nutrients entering at some point upstream) and had a fair number of nonnative species associated with it, the stream was still very functional and supported a diversity of organisms. The health and the diversity of the stream remained consistent along the stretch examined and there did not visibly appear to be an impact adjacent to or downstream of the slag or Site when compared to locations upstream.

The surveys were qualitative in nature so can only be used in a qualitative sense to aid in evaluating potential risks to benthic macroinvertebrates in the Agua Fria River.

10.3.3.3 Identification of COECs

Based on the available chemical monitoring data collected during the RI, and considering all additional lines of evidence as described in Section 10.3.3.2 (Risk Description), those COPECs identified as posing unacceptable ecological risk at the Site are retained as COECs and recommended for further evaluation in the forthcoming FS.

Chemicals with site HQs exceeding 1 for at least one receptor for any benchmark or TRV are presented for each exposure area for soils (Table 10-6), sediments (Table 10-7), and surface water (Table 10-8). Weight-of-evidence for retaining or excluding the chemical as a COEC is based on incremental risk estimates (where available) and site risk estimates where incremental risks could not be computed. Otherwise, site risks were used. Identification of COECs for soil, sediment, and surface water exposure pathways is presented below:

Soil Exposure Pathways

Chemicals with incremental HQs (where available) or Site HQs exceeding 1 for at least one receptor for any benchmark or TRV are presented for each soil exposure area in Table 10-6. Rationale for retaining or excluding the chemical as a COEC is presented as follows:

- Weight-of-evidence code "A" – Chemical is retained as a COEC. Chemicals with LOAEL-based HQs greater than 1 for at least one bird or mammal receptor and do not fall under any weight-of-evidence exclusions were retained as COECs.
- Weight-of-evidence code "B" – Chemical was not retained as a COEC. Chemicals for which the incremental (or site HQs) for plants, soil invertebrates, birds, and mammals (LOAEL-based) are less than 1 (rounded to one significant figure) are considered within acceptable risk levels and were not retained as COECs.
- Weight-of-evidence code "C" – Chemical was not retained as a COEC. LOAEL-based HQs are less than one for birds and mammals. HQs for plants and soil invertebrates may exceed one, but are less than 10, indicating a low potential for risk to these receptors. In addition, plants and soil invertebrates are not used as the sole determinant for retention, because of uncertainties in toxicity values. Results of risk estimates for birds and mammals are given greater weight. Because no LOAEL-based HQs exceed 1, the chemical is not retained as a COEC.
- Weight-of-evidence code "D" – Chemical was not retained as a COEC. Aluminum is not considered a risk to ecological receptors when soil pH is greater than 5.5 (EPA, 2003c). The average pH for site soils (0 to 2 feet bgs) is greater than 5.5.
- Weight-of-evidence code "E" – Chemical was retained as a COEC. Aluminum is considered a risk to ecological receptors when soil pH is less than 5.5 (EPA, 2003c). The average pH for site soils (0 to 2 feet bgs) is less than 5.5, so aluminum is retained as a COEC.
- Weight-of-evidence code "F" – Chemical was not retained as a COEC. Potential toxicity of aluminum is based on soil pH; however, soil pH data are not available for this exposure area. The sitewide average pH (6.2) is considered applicable for this exposure area because this exposure area does not border one with a pH is less than 5.5 and no other COECs were identified for the exposure area.

COECs identified after the weight-of-evidence evaluation are summarized in Table 10-9. An overall estimate of the magnitude of soil-based risks for each exposure area is presented on Figure 10-7. The color codes are subjective only and are based on evaluation of the magnitude of estimated risks, number of COECs, and receptors showing potential for adverse effects.

Sediment Exposure Pathways

Chemicals with site HQs exceeding one for at least one receptor for any benchmark or TRV are presented for each sediment exposure area in Table 10-7. Rationales for retaining or excluding the chemical as a COEC are presented as follows:

- Weight-of-evidence code "A" – Chemical was retained as a COEC. Chemicals with Site HQs exceeding 1 (rounded to one significant figure) at the LOAEL (birds and mammals) and effects-based benchmarks (benthic macroinvertebrates) and that do not fall under any weight-of-evidence exclusions were retained as COECs.

- Weight-of-evidence code "B" – Chemical was not retained as a COEC. The plant HQ and all LOAEL-based HQs (macroinvertebrates, birds, and mammals) were less than 1 (rounded to one significant figure).
- Weight-of-evidence code "C" – Chemical was not retained as a COEC. LOAEL-based HQs were less than 1 for macroinvertebrates, birds, and mammals. Plant HQ exceeds 1, but potential risk to plants is not used as the sole determinant for retention because of uncertainties in toxicity values for these receptors.
- Weight-of-evidence code "D" – Chemical was not retained as a COEC. Aluminum is not considered a risk to ecological receptors when soil and sediment pH is greater than 5.5 (EPA, 2003c). The average pH for the exposure area is greater than 5.5.

COECs identified for the Agua Fria River after the weight-of-evidence evaluation are summarized in Table 10-9. An overall estimate of the magnitude of sediment-based risks for each exposure area is presented on Figures 10-8 (arsenic), 10-9 (copper), and 10-10 (lead). The color codes are subjective based on evaluation of the magnitude of estimated risks, number of COECs, and receptors showing potential for adverse effects.

As noted above, localized hot spots drive the overall risks for sediments, with the highest potential risks occurring in exposure area AF-02. As can be seen on Figures 10-8 through 10-10, localized hot spots occur near the former Humboldt Smelter property source areas and the confluence with Chaparral Gulch. In exposure area AF-02, the stretch of the Agua Fria River between locations OW-20 and AF-5 runs adjacent to the slag piles in an area where dross and slag from the former Humboldt Smelter property extend down to the Agua Fria River. In exposure area AF-03, location AF-12 is a localized hot spot just downstream of the confluence with Chaparral Gulch. This location was resampled during a subsequent field effort, and concentrations were lower by an order of magnitude in the resample, indicating that impacts to this stretch of the Agua Fria River are localized, the sediment material in this area is transient, or a combination of both factors (EA, 2010).

Surface Water Exposure Pathways

Chemicals with Site HQs exceeding 1 for at least one receptor are presented for each surface water exposure area in Table 10-8. The rationale for retaining or excluding the chemical as a COEC is presented as follows:

- Weight-of-evidence code "A" – Chemical was retained as a COEC. Chemicals with chronic HQs exceeding 1 and, for which, the estimated risk exceeds that for the upstream reference locations.
- Weight-of-evidence code "B" – Chemical was retained as a COEC based on comparison to upstream reference locations. The benchmark used to assess potential risks is a secondary or Tier II value. There is a higher level of uncertainty and conservatism associated with the Tier II Values, because the Tier II values were established with fewer data than are required for the NRWQC, and are generally expected to be lower than NRWQC.
- Weight-of-evidence code "C" – Chemical was not retained as a COEC. Site HQ is equal to or less than the maximum upstream reference locations HQs.

COECs identified for the Agua Fria River after the weight-of-evidence evaluation are summarized in Table 10-9. It should be recognized that some of these constituents could be contributed by the naturally mineralized conditions prevalent in the region, rather than specifically from mine- or smelter-related sources. Moreover, most of the flow in the Agua Fria River upstream of the Site consists of effluent from the Prescott Valley Wastewater Treatment Plant, except possibly during higher flow storm events.

10.3.3.4 Uncertainty Analysis

Uncertainties are inherent in all ecological risk assessments because of the limitations of the available data and the need to make certain assumptions and extrapolations based on incomplete information. In addition, the use of various models (for example, uptake and food web exposures) carries with it some associated uncertainty as to how well the model reflects actual conditions. However, because conservative assumptions are generally used throughout the exposure and effects assessments, these uncertainties are more likely to result in an overestimation rather than an underestimation of the likelihood and magnitude of risks to ecological receptor. The uncertainties and limitations associated with the BERA are summarized in Table 10-10.

10.3.4 SMDP 2

This BERA was conducted in accordance with EPA guidance. Risks were estimated for the most representative ecological receptors and pathways of ecological exposure, based on available RI sampling data and a current understanding of habitats and ecosystems present at the Iron King Mine – Humboldt Smelter Superfund Site. The BERA indicated that there is a potential for adverse risk to ecological receptors from selected metals detected in soil, sediment, and surface water at the Site. Chemicals identified as COECs after the weight-of-evidence evaluation (including potential risk from background concentrations) are summarized in Table 10-9. These metals are recommended for risk management consideration, and the evaluation of actions to address the associated ecological exposure pathways in the forthcoming FS for the Site.

SECTION 11

Summary and Conclusions

This section provides a summary of the work completed in development of this RI. It lists significant findings regarding the nature and extent of contamination and the fate and transport of the contaminants, and identifies areas where the potential for risk from exposure to site-related contamination exists. Finally, this section provides conclusions and recommendations for addressing these site conditions during the planned FS.

11.1 Summary of the RI Work Completed

This RI Report documents the history of the Iron King Mine – Humboldt Smelter Superfund Site from the beginning of operations in the 1870s through numerous investigations and enforcement actions beginning in 2001.

The former Iron King Mine and the former Humboldt Smelter properties are located within the Town of Dewey-Humboldt, Arizona, about 85 miles north of Phoenix (Figure 1-1). The contaminant sources at the former mine and smelter properties are associated with stockpiled mine and smelter waste created during a long history of operations (Section 2). Site contaminants, primarily metals such as lead and arsenic, have impacted neighboring non-residential, residential, and municipal properties. Contaminants have been transported by surface water discharges into Chaparral Gulch, Galena Gulch, and their tributaries.

Regulatory involvement at the Site began with EPA and ADEQ inspections associated with stormwater and air quality permit compliance (Section 3). Regulatory inspections documented unauthorized discharges of stormwater and tailings to surface water bodies and dust emissions at the former Iron King Mine and Humboldt Smelter properties. Following completion of preliminary assessments and site investigations between 2001 and 2006, and evaluation of the data using EPA's Hazard Ranking System, the Site was formally placed on EPA's NPL in September 2008 (Section 3).

During the course of the four phases of the RI investigations (Section 4), over 6,300 soil samples were collected from residential properties, and more than 2,300 soil samples were collected from non-residential areas. On a sitewide basis, approximately 193 sediment, 102 surface water, 219 groundwater, and 224 air samples were collected. Laboratory testing conducted on these samples included analytical, geotechnical, and geochemical testing. The laboratory test results were compiled into a database.

In conjunction with the field investigations and review of geologic mapping, physical site characteristics were defined (Section 5). An area of potential site impact (the "APSI") was established based on a study of background concentrations of site-related constituents in soils (Appendix E); COIs and screening levels were identified (Section 6). For soil, the APSI was subdivided into discrete exposure areas based on current or future land use, former operations, source materials, and property boundaries (Section 6.6).

The nature and extent of COIs in soil was evaluated for each exposure area, and on a sitewide basis for sediment, surface water, ambient air, and groundwater (Section 7). Tables and figures were developed presenting the results of the analyses and illustrating the distribution of contaminants in each exposure area. Estimates of the volume of contaminated materials were developed during the RI and are presented in Section 7.2.5. These estimates will need to be reevaluated during preparation of the FS to account for data and information developed during all phases of the RI.

Analytical and geochemical data including ABA and NP were used in conjunction with the history of the Site and the estimated nature and extent of contamination to develop an understanding of the potential pathways that these contaminants may move in the environment; that is, their fate and transport (Section 8).

A baseline HHRA identified and characterized the toxicity of the COPCs, the potential exposure pathways, the potential human receptors, and the likelihood of adverse health effects under current and reasonably anticipated future land and water use (Section 9). A baseline ERA analyzed potential current or future adverse effects to ecological receptors from chemical substances released from the Site, in the absence of any actions to control or mitigate those releases (Section 10).

11.2 Nature and Extent of Contamination

Contaminant sources at the Iron King Mine – Humboldt Smelter Superfund Site include:

- Underground mining and the production of ore, waste rock, and waste transmitted by surface discharges and air dispersion at the former Iron King Mine property
- Ore processing, smelting, production of tailings and smelter waste, and air emissions from smelter stacks at the former Humboldt Smelter property
- Release of tailings and other waste materials to the environment at both properties

Site contaminants, primarily lead and arsenic, were released to the environment through direct discharge during operations, discharge from tailings dams and impoundments during routine operations and overflow during storm events, placement of mine and smelter waste in drainages, smelter stack emissions and windblown particulates, impoundment failures, erosion during storm events, spills during transport along conveyors and rail routes, and the use of mine waste material as fill material and road base. The contaminants have been found in soil and sediment, and to a lesser extent, in surface water, groundwater, and ambient air.

Impacted areas include: (1) the former Iron King Mine and Humboldt Smelter properties, (2) peripheral or undeveloped areas, (3) Galena Gulch, (4) Chaparral Gulch, (5) the Agua Fria River; and (6) non-residential and residential parcels within the Town of Dewey-Humboldt.

The following sections provide a general overview of the contaminants found in soil, sediment, surface water, groundwater, and ambient air at the Site. Section 7, and the accompanying tables and figures, provides a detailed review and analysis of the data. Figure 6-3 shows the location of the exposure areas.

11.2.1 Sitewide Soil Contamination

11.2.1.1 Former Iron King Mine Property

The Iron King Mine exploited a massive sulfide deposit that primarily produced lead and zinc. The ore was composed primarily of iron sulfide (pyrite) along with zinc and lead sulfide minerals, with lesser amounts of copper, silver, and gold. Ore was mined from shafts and stopes over 3,000 feet deep, and was processed at the site since the late 1800s. At one-time, Iron King Mine was the largest producer of lead and zinc in Arizona, producing 6.3 million tons of ore, 232 million pounds of lead, 614 million pounds of zinc, 30 million pounds of copper and silver, and nearly ½ million ounces of gold (USGS, 1995). Most of this production took place from the late 1930s through the 1960s.

Historical aerial photographs (Appendix C) and mine maps (Appendix O) show processing facilities, impoundments, waste rock, and tailings impoundments located throughout the property. These facilities discharged waste into the drainage adjacent to Third Street, and to both the Chaparral and Galena Gulches.

MTP (NR17). The MTP, in place prior to 1964, presently occupies an area of about 55 acres and contains about 3.5 million yd^3. The tailings are classified predominantly as silt (ML) or silty sand (SM) and are generally non-plastic. Monitoring data, last obtained in 2014, indicate that the tailings are not saturated and that the water table is near the bottom of the tailings. A major slope failure occurred at the MTP in 1964 and is referred to as the "MTP 1964 Blow Out." The mine manager, in a letter to the mine company management (Kentro, 1964), stated that while it was difficult to estimate, "a reasonable guess" would be that 5,000 tons entered into the Agua Fria River. This material and contaminated water were discharged from the MTP into downstream areas through the following exposures areas (shown on Figure 6-3):

- NR4 JT Septic Facility
- NR5 MTP 1964 Blow Out Path
- NR3 Upper Chaparral Gulch

The slope failure was halted in its progress by the old railroad grade. The MTP now ranges in depth from about 100 feet in the upper MTP to about 60 feet in the lower MTP, with a 2:1 slope over 50 feet high separating the upper and lower MTP.

The maximum arsenic and lead concentrations, and the greatest proportion of contaminated soils samples collected at the Site during the RIs, were found at the MTP and the former Iron King Mine property. The maximum arsenic concentration equaled 13,000 mg/kg at boring location B-3 at a depth of 4.5 feet. The maximum lead concentration equaled 24,000 mg/kg at boring location B-2 at a depth of 14.5 feet. All of the samples from the MTP exceeded the screening level for arsenic (194 mg/kg) and for lead (400 mg/kg). The average arsenic concentration for the 79 surface and subsurface samples equaled 3,974 mg/kg. The average lead concentration equaled 3,449 mg/kg.

Former Mineworks area (NR16). Within the former Mineworks area, elevated arsenic and lead in the surface and subsurface soil is attributed to the dumping and placement of mine waste and processed wastes, as well as waste rock from the excavation of mine shafts. Within this area (shown on Figure 6-3), more than half the samples exceeded the arsenic and lead screening levels. For those samples above the screening level, average concentrations of arsenic and lead equaled 1,026 and 5,134 mg/kg, respectively. Based on preliminary estimates prepared during the RIs (Section 7.2.5), NR16 contains approximately 101,900 yd^3 of waste rock and impacted soil.

Former Glory Hole and North of MTP (NR19). To the north of the MTP and the former Mineworks areas, collapse of the mine workings produced a Glory Hole that has been used as a landfill and filled with municipal waste, construction debris, and tires. Other portions of the exposure area (shown on Figure 6-3) contain former impoundments and a slurry line from the mine workings to the location of a Small Tailings Pile that was removed in 2011. Not including samples from the former Small Tailings Pile, nearly 30 percent of the samples collected from NR19 during the RIs exceeded the arsenic screening level; 12 percent exceeded the lead screening level. For those samples above the screening level, average arsenic concentration equaled 423 mg/kg and average lead concentration equaled 1,286 mg/kg. Based on the volume estimates prepared during the RIs, NR19 contains approximately 7,400 yd^3 of waste rock and impacted soil.

South of Former Iron King Mine Property (NR14). To the south of the MTP and former Mineworks areas, mine shafts, waste dumps, and small impoundments were located as early as 1940 (Appendix C), and discharges from these facilities were conveyed toward Galena Gulch. The area (shown on Figure 6-3) is now vacant and undeveloped. Of the samples collected from NR14, more than 40 percent exceeded the arsenic screening level and 24 percent exceeded the lead screening level. For those sample above the screening level, the average arsenic and lead concentrations equaled 903 and 2,513 mg/kg. Based on preliminary estimates prepared during the RIs, NR14 contains approximately 37,000 yd^3 of waste rock and impacted soil.

NAI Operations Area (NR18). Within this area (shown on Figure 6-3), tailings from the MTP are processed to produce a liquid fertilizer product. Several stormwater retention ponds within NR18 control surface water flow around the MTP and the NAI Operations area. Elevated levels of arsenic and lead were found in this exposure area. Of the samples collected from NR18, more than 40 percent exceeded the arsenic screening level and 13 percent exceeded the lead screening level. For those samples above the screening level, the average concentrations equaled 376 and 3,047 mg/kg for arsenic and lead, respectively. Based on preliminary estimates prepared during the RIs, NR18 contains approximately 19,200 yd^3 of waste rock and impacted soil.

11.2.1.2 JT Septic Facility and MTP 1964 Blow Out Path

Sampling and testing within exposure areas downgradient from the former Iron King Mine property demonstrate that tailings from the MTP are present in the JT Septic Facility (NR4) and the MTP 1964 Blow Out Path (NR5). These areas (shown on Figure 6-3) both contain soils with elevated arsenic and lead. Tailings are visible in the yard at the corner of Third Street and Omega Drive, and within the drainage ditch on the south side of Third Street across from Richards Lane. Two subsurface samples across from Richards Lane had arsenic concentrations of 540 and 443 mg/kg, both well above background and screening levels. Lead concentrations greater than 10,000 mg/kg were found in surface samples located on the south side of Third Street near the center of the NR5 exposure area.

11.2.1.3 Middle Chaparral Gulch

Downstream from NR5, elevated arsenic and lead are found in surface and subsurface soils in the Middle Chaparral Gulch (NR6) (shown on Figure 6-3). Aerial photographs (Appendix C) and the soils data (Section 7) indicate that NR6 was impacted by tailings and process-impacted water from the former Iron King Mine operations and by tailings discharged during the MTP 1964 Blow Out. The Middle Chaparral Gulch consists of several active channels incised into alluvial channel fill. Tailings are present within the gulch along the banks within the middle and eastern edge of the channel, and outside the southern channel likely through overbank deposition of the tailings and erosion of previously deposited tailings. Review of the surface and subsurface data shows that mining-impacted soil has been deposited intermittently with non-impacted material throughout the exposure area.

11.2.1.4 Tailings Floodplain

The Tailings Floodplain (NR8) is located downstream of Middle Chaparral Gulch (Figure 6-3). It extends from the southern boundary of the Smelter Tailings Swale (NR7) to below the Chaparral Gulch Dam. The Tailings Floodplain has been impacted by discharges of tailings from the former Iron King Mine property, including the MTP 1964 Blow Out, and tailings associated with operations at the former Humboldt Smelter property. Similar to that observed in the Middle Chaparral Gulch, the deposits consist of an interbedded mixture of tailings and less-impacted material, likely conveyed from Chaparral Gulch upstream of State Highway 69 during large storm events.

Surface and subsurface samples with elevated arsenic and lead are present throughout the Tailings Floodplain. Elevated concentrations of arsenic were found in both surface and subsurface soils. While elevated concentrations of lead were found in some surface samples, most of the elevated lead concentrations were found in subsurface samples. The distribution within the floodplain appears to change from upstream to downstream. As shown on Figures 7-24, 7-25, 7-26B, and 7-27B, in the upstream area, nearest the Middle Chaparral Gulch, elevated arsenic and lead were found mostly near the centerline trace of the Chaparral Gulch. Downstream of this area, elevated concentrations were found near the centerline and on the southwest perimeter of the floodplain. Near the Chaparral Gulch Dam, surface samples had lower arsenic and lead, with most of the elevated concentrations found below surface.

Over the entire Tailings Floodplain, for those samples that exceeded the screening level, subsurface samples had an average arsenic concentration almost double that of surface samples. Only 15 percent of the 33 samples that exceeded arsenic concentrations greater than 1,000 mg/kg were surface samples, the remainder were subsurface. The maximum arsenic concentration (3,640 mg/kg) was recorded at a depth of 7.5 feet just upstream from the Chaparral Gulch Dam. As observed with respect to the arsenic distribution, many more subsurface samples had high lead concentrations compared to subsurface samples. About 25 percent of the samples with lead concentrations greater than 1,000 mg/kg were surface samples, the remainder were subsurface samples. The maximum lead concentration in the Tailings Floodplain (45,900 mg/kg) was recorded at a depth of 10 feet bgs just upstream from the Chaparral Gulch Dam.

The Chaparral Gulch Dam impounds tailings and native alluvial deposits. The deposits increase in thickness approaching the dam, where the floodplain is more confined and the saturated thickness exceeds 20 feet. Little or no storage capacity remains behind the dam because of the accumulation of tailings and alluvium, which can continue to migrate downstream to the Agua Fria River. Efflorescent salts are present on the exposed tailings floodplain. These salts form by repeated cycles of wetting and drying, which concentrates metals in a highly mobile form. The dam restricts groundwater flow in the saturated sediment behind the dam; however, seepage discharges from the toe of the dam throughout the year. Just below the Chaparral Gulch Dam, and for a distance of about 50 yards downstream, red precipitate is present on the streambed and on surface soils adjacent to the stream (Photograph 22 in Appendix A).

Based on estimates prepared during the ERT investigation (2014), NR8 contains approximately 175,000 yd^3 of tailings (Section 7.2.5), in addition to tailings impacted soil. The stability of the dam, and conformance with dam safety requirements, will need to be addressed during preparation of the FS.

11.2.1.5 Former Pyrometallurgical Operations Area

The former Pyrometallurgical Operations area (NR11) (shown on Figure 6-3) encompasses the former Humboldt Smelter property where the majority of the smelting operations took place. Operations began in 1876 at the former Humboldt Smelter property (milling and smelting of local ore for silver), with peak production (primarily smelting copper) between 1899 and 1920. Ore was received in rail shipments and offloaded within the northern portion of the property where the ore was processed to form copper concentrates. The concentrate was melted in furnaces, molten slag separated from molten copper, and molten copper refined to ingots in a series of converters. Tailings from the ore concentrators were discharged into impoundments located throughout the area, with most of the tailings placed behind berms on the Smelter Tailings Swale (NR7). Samples collected within NR11 were classified as tailings, dross, ash pile, slag, Hickey Formation, and native soils. Elevated arsenic and lead concentrations were found primarily:

- Within the northern portion of NR11 in the area of the rail trestle, ore conveyors, and crushers
- In the upper middle portion of NR11 in the area of the former converters and smelters
- At the perimeter of NR11 to the northeast within the impoundment
- Toward the west on the Smelter Tailings Swale, where tailings were placed behind berms or dams that have since failed

For all samples collected, the average concentrations of arsenic and lead equaled 709 mg/kg and 1,409 mg/kg, respectively. Twenty-two percent of the samples exceeded the screening level for arsenic, while 53 percent of the samples exceeded the screening level for lead. The area is now covered with a thin layer of dross, a fine- to medium-grained material imported after closure and dismantling of the Humboldt Smelter plant for reprocessing to recover aluminum and zinc.

Slag deposits consist of black, brownish black, and bluish green glassy (amorphous) material. The slag appears to have been dumped as solidified blocks, portions that have been subsequently weathered to gravel or boulder-sized pieces. Other portions of the slag pile appear to have been placed while molten, forming sheets and flows, which later solidified. The slag deposits have formed a steep bluff overhanging the Agua Fria River. Slope failures have occurred, and the slag extends down to the edge of the Agua Fria River in places.

11.2.1.6 Smelter Plateau

The Smelter Plateau (NR12) (shown on Figure 6-3) is located south of the former Pyrometallurgical Operations area. This area was the site of the earliest mining operations, prior to construction of the Humboldt Smelter. The Chaparral Gulch Shaft mine was located in the southeastern portion of the Smelter Plateau, providing ore to the Agua Fria Ore Mill and Smelter in the 1870s and 1880s. Tailings from these operations were deposited in a tailings pile located at the downstream end of the Lower Chaparral Gulch (NR9) and at the Agua Fria Tailings Pile (NR10) located adjacent to the Agua Fria River. Both of these tailings piles contain elevated levels of arsenic and lead.

Residential housing, known as Nob Hill, was built in the early 1900s for smelter managers. Remains of tennis courts and home foundations are still present in the area. Piles of dross are exposed on the plateau, and a small slag pile is located along the eastern edge of the plateau, upslope from the Agua Fria River. A tailings pile is located in the former housing area.

At the tailings deposits visible in the Lower Chaparral Gulch canyon, approximately 800 feet downstream of the Chaparral Gulch Dam and upstream of its confluence with the Agua Fria River, the average arsenic concentration for the 24 surface samples equaled 539 mg/kg. For the 11 samples that exceeded the arsenic screening level of 194 mg/kg, the average concentration equaled 1,049 mg/kg. The average lead concentration equaled 649 mg/kg. For the seven samples that exceeded the lead screening level of 400 mg/kg, the average concentration equaled 1,827 mg/kg. Two samples had lead concentrations greater than 3,500 mg/kg.

At the Agua Fria Tailings Pile (NR10), 8 of 13 samples exceeded the screening level for arsenic, and 9 exceeded the screening level for lead. For the samples that exceeded the screening level, the average arsenic and lead concentrations equaled 3,202 mg/kg and 5,556 mg/kg, respectively.

11.2.1.7 Smelter Tailings Swale

The Smelter Tailings Swale (shown on Figure 6-3) was used to store or dispose of tailings produced as a waste product from concentrating the ore. Historical aerial photographs (Appendix C) indicate the presence of several small dams and impoundments within the swale, all of which failed by 1940. The exact dates of the failures are not known and these events could have taken place any time within the 30 years prior to 1940.The largest berm is visible across the bottom of the swale. Its failure has left a gully about 15 feet deep, visible in Photograph 14 in Appendix A. Remnant tailings within the swale are up to 12 feet thick. The ERT RI (Lockheed Martin SERAS, 2015) estimated that more than 14,000 yd^3 of tailings remain on the slope.

Only about 25 percent of the soil samples had arsenic concentrations greater than the screening level. Only two samples had arsenic concentrations greater than 325 mg/kg. Lead concentrations followed a similar pattern as that found for arsenic. Only 12 percent had lead concentrations greater than the screening level (400 mg/kg).

11.2.1.8 Residential

Potential site-related sources of contaminants include: (1) transport of contamination from the former mine/smelter property source areas to residential areas via windblown dust, tailings, dross, and impacted soil; (2) particulate stack emissions; (3) surface water transport and deposition along Chaparral Gulch; (4) spills and material releases along historical rail routes; (5) use of waste material as fill at residential properties; and (6) redistribution of contamination through development.

Non-site-related sources include (1) naturally occurring arsenic (and other metals) associated with silicic volcanic materials such as rhyolite, which are widely present within the region; (2) fill imported from quarries with naturally elevated concentrations of arsenic; (3) cut-and-fill activities in areas of naturally elevated concentrations of arsenic east of the Agua Fria River; and (4) use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires.

The result of site-related and non-site-related sources of metals, in addition to the redistribution of contamination during development, has resulted in a complex patchwork distribution of metals in residential areas. For this reason, multiple phases of sampling were performed in residential areas, with the most extensive sampling efforts occurring between 2008 and 2012, and between 2013 and 2014. In total, approximately 6,300 soil samples were collected from residential properties within the APSI.

Residential Yard-Specific Risk (RYSR) Exposure Areas. For RYSR areas, sampling was performed and analytical results were evaluated on a yard-by-yard basis. For RSAR areas, properties located near the boundary of the APSI, and less likely to have been impacted by the Site, were divided into manageable screening subareas labeled A through J. Each screening area contained many contiguous properties. The investigation plan included the contingency that if the overall site-related risk, or even high individual values, emerged from the screening investigation, then the screening area would be converted to an RYSR area and all properties in the area would be sampled. If the area characterized as a whole posed only low residential risks and had no significantly elevated levels, then yard-by-yard sampling would be unnecessary. Each screening area was sampled and a screening evaluation was done. EPA took care to ensure that samples were reasonably and representatively spread across the entire area.

For the RYSR exposure areas, the largest concentrations of arsenic and lead in soil samples were detected in areas surrounding the former Humboldt Smelter property, and areas that overlap or are adjacent to the Upper or Middle Chaparral Gulch. In general, where arsenic or lead concentrations are elevated in shallow soil samples collected off the mine and smelter properties, their concentrations are lower in the collocated deeper samples, which is consistent with aerial deposition of windblown dusts and smelter emissions. Exceptions include areas were deeper soil contamination is known to occur, including along the former Smelter Spur, the Tailings Floodplain of Chaparral Gulch, and the confluence of the MTP Blow Out Path and Upper Chaparral Gulch into Middle Chaparral Gulch. Anthropogenic factors, such as grading for property development and importing fill for landscaping, may have altered the distribution of arsenic and lead in the downwind areas.

Fill has been imported from quarries with naturally elevated concentrations of arsenic and grading or cut-and-fill activities have occurred in areas of naturally elevated concentrations of arsenic east of the Agua Fria River and south of the former Humboldt Smelter property in the Maggy Trail residential area. Of the 384 yards sampled, 19 yards have an arsenic EPC that exceeds the screening level, 90 yards have a lead EPC that exceeds the provisional RSL, and 28 yards have a lead EPC that exceeds the residential RSL.

The HHRA (Section 9 and related figures, tables, and appendices) evaluates for RYSR properties yard-by-yard EPCs, incremental ELCRs for all contaminants (this is driven by arsenic), and noncancer HIs for all contaminants, adjusted for organ endpoint where necessary.

Residential Screening Area Risk (RSAR) Exposure Areas. For RSAR exposure areas, although some arsenic or lead concentrations exceed background or screening levels in discrete samples, the calculated

EPCs (across the areas) do not exceed screening levels, with the exception of a hot spot area at a stormwater diversion berm known to be made using imported mine tailings in RSAR-D. Otherwise, the calculated EPCs for all RSAR areas were below screening levels. Only 1 of 279 samples marginally exceeded the screening level and background value for arsenic (227 mg/kg compared to screening level of 194 mg/kg). Although 28 percent of the samples in the RSAR exposure areas exceeded the lead background value, all samples were below the residential RSL of 400 mg/kg, and only one sample exceeded the provisional RSL of 140 mg/kg.

11.2.2 Sediment

Samples identified as sediment were collected from Chaparral Gulch, Galena Gulch, the Agua Fria River, sporadically ponded areas, onsite retention ponds, and ancillary drainage pathways on or near the former Iron King Mine and former Humboldt Smelter properties. Many of these samples were located in areas more indicative of terrestrial habitat, rather than aquatic or benthic organism habitat. However, as discussed in Section 6.3.2 and listed in Table 6-3, sediment sample results were screened against criteria for the protection of benthic organisms; these concentrations are much lower that the screening levels for soil. Primary COIs in sediment include arsenic, copper, lead, mercury, and zinc.

Upstream reaches of Galena Gulch, Chaparral Gulch, and the Agua Fria River were sampled in September 2008 (EA, 2010). Samples were collected upstream of the former Iron King Mine property in Chaparral Gulch and Galena Gulch and upstream of the drainage ditch emanating from the former Humboldt Smelter property in the Agua Fria River. These are identified as “upstream” samples in Table 7-16. Sitewide primary COIs with the lowest concentrations were detected in upstream reaches of the Agua Fria River, Chaparral Gulch, and Galena Gulch. Mercury and lead concentrations were below screening levels in all upstream samples; zinc exceeded screening levels in only two samples from Galena Gulch. In contrast, arsenic concentrations exceeded the screening level of 9.79 mg/kg in upstream samples from Galena Gulch and Chaparral Gulch, and the majority of upstream samples from Agua Fria River. Copper concentrations exceeded the screening level of 31.6 mg/kg in all background samples from Galena Gulch, four of the samples from the Agua Fria River, and one of the samples from Chaparral Gulch.

11.2.2.1 Chaparral Gulch and Galena Gulch

The Chaparral Gulch and Galena Gulch drainage basins have been widely impacted by site-related contamination, as evidenced by the distribution of the primary COIs in sediment samples relative to the Iron King Mine and Humboldt Smelter source areas. The lowest concentrations of the primary COIs were detected in upstream reaches of Galena Gulch and Chaparral Gulch, upstream of the former Iron King Mine property. The maximum concentrations of arsenic, lead, mercury, and zinc were detected in former Iron King Mine property source areas.

Chaparral Gulch sediment sample locations included areas upstream of the Tailings Floodplain, the Tailings Floodplain, and Lower Chaparral Gulch. As shown on Figures 7-37 through 7-41, concentrations of arsenic, lead, copper, zinc, and mercury exceeded sediment screening levels in much of Chaparral Gulch and were greatest in the area of the Tailings Floodplain and Chaparral Gulch Dam.

Concentrations of the primary COIs in sediment in Galena Gulch were greatest on the back slope of the former Fertilizer Plant area. Many of the sediment samples with elevated concentrations of arsenic and lead were described as tailings material during the initial phase of the RI (EA, 2010). Downstream of the former Iron King Mine property, most of the Galena Gulch is largely devoid of sediment, as it lies on the surface of scoured bedrock. Concentrations in sediment samples decrease significantly; however, concentrations remain above sediment screening levels in the samples collected just downstream of State Highway 69.

11.2.2.2 Agua Fria River

Concentrations of the primary COIs were generally below screening levels in the upgradient Agua Fria River locations, with the exception of arsenic and copper. The upgradient data, along with the sitewide soil background data, indicate there are naturally occurring sources of arsenic and copper at concentrations exceeding sediment screening levels.

Site-related contamination in the sediments sampled adjacent to or within the Agua Fria River is primarily limited to locations near the former Humboldt Smelter property source areas (in an area where dross and slag from the Humboldt Smelter extend down to the Agua Fria River). Chaparral Gulch is a source of impacted material to the Agua Fria River, as shown by the increase in concentrations of the primary COIs downgradient of the confluence.

Erosion of material from the Agua Fria Tailings Pile and historical impacts from predecessor operations at the former Agua Fria Mill (Figure 2-2) are other possible sources of impacted sediment in the Agua Fria River near or downstream of the confluence with Chaparral Gulch. A localized hot spot just downstream of the confluence with Chaparral Gulch was resampled during a subsequent field effort, and concentrations were lower by an order of magnitude in the resample. These data indicate that the impacts to this stretch of the Agua Fria River may be localized or that the sediment material in this area with elevated concentrations may have moved in response to flow conditions in the river, or a combination of both factors.

11.2.3 Surface Water

Surface water in Chaparral Gulch, Galena Gulch, and the Agua Fria River have been impacted by site-related contamination from the former Iron King Mine and Humboldt Smelter properties. Primary COIs in surface water include arsenic, copper, iron, lead, and zinc.

11.2.3.1 Chaparral Gulch and Galena Gulch

Surface water within the Chaparral Gulch and Galena Gulch drainage basins has been widely impacted by site-related contamination, as evidenced by the distribution of the primary COIs relative to the former Iron King Mine and Humboldt Smelter property source areas. The highest concentrations were detected on, and adjacent to, former Iron King Mine and Humboldt Smelter property source areas. Concentrations of the primary COIs exceeded screening levels in most of the downstream portions of Chaparral Gulch and Galena Gulch. Samples were screened against water quality goals for the protection of aquatic organisms as a conservative approach; however, it should be noted that the Chaparral Gulch and Galena Gulch are intermittent drainages, and are not covered with water a sufficient amount of time to support aquatic organisms.

11.2.3.2 Agua Fria River

Site-related contamination in the Agua Fria River is limited to locations adjacent to the former Pyrometallurgical Operations area (NR11) and at (and immediately downstream of) the confluence with Chaparral Gulch. Concentrations of the primary COIs were below screening levels in the furthest downstream locations in the Agua Fria River. Sulfate, which is an indicator of ARD generation, was low (below 100 mg/L) in all reaches of the Agua Fria River.

Concentrations of some metals exceeded the screening levels in a large number of samples and had comparable concentrations both upstream and downstream of the Iron King Mine and Humboldt Smelter source areas, suggesting the potential for elevated concentrations in surface water. As an example, 95 percent of samples exceeded screening levels for barium, including all samples collected from upstream reaches of the Agua Fria River. Most of the flow in the Agua Fria River upstream of the Town of Dewey-Humboldt consists of effluent from the Prescott Valley Wastewater Treatment Plant, except possibly during higher-flow storm events. In addition, there are upstream agricultural uses, and local geology results in elevated mineralization in soils and alluvial materials eroded from these areas.

11.2.4 Groundwater

Groundwater sampling data were collected between 2002 and 2014 from monitoring and water supply wells. Primary COIs in groundwater include arsenic, lead, nitrate, sulfate, and TDS. The following is a summary of the significant RI findings for groundwater:

- Elevated sulfate concentrations most consistently demarcate groundwater impacted by ARD generation. The area of impact is limited to the shallow groundwater zones beneath and between the mine and smelter properties and along Chaparral Gulch. Sulfate concentrations in the deeper Precambrian bedrock monitoring wells beneath and near the former Iron King Mine and Humboldt Smelter properties are not elevated and the water chemistry signature is distinctly different, indicating a lack of hydraulic communication between the shallow groundwater and the deeper fractured Precambrian bedrock.
- The groundwater pH is slightly lower in areas where elevated sulfate concentrations occur, but repeatable pH values below 6 were not observed, indicating that residual neutralizing capacity in waste materials, as well as local soils and groundwater matrix minerals, are buffering the ARD acidity.
- ARD impacts from metals are more localized than sulfate. Arsenic, lead, and TDS locally exceed screening levels in shallow groundwater underlying and immediately downgradient of the MTP, and in the saturated tailings-impacted alluvium impounded upstream of the Chaparral Gulch Dam.
- Groundwater in the vicinity of the Humboldt Smelter is locally impacted by chloride, nitrate, and TDS. These exceedances may be related to releases of wastewater associated with dross processing, leaching of exposed dross, or a combination of these processes. The TDS, chloride, and nitrate impacts associated with the Humboldt Smelter site may extend off property to nearby domestic wells.
- Regional impacts to groundwater, not related to the Site, include elevated arsenic concentrations in public and private supply wells and EPA bedrock monitoring wells that are associated with natural mineral sources in the area. The majority of private and public supply wells in Humboldt Proper near the Site have arsenic concentrations below the MCL. Where exceedances do occur, the concentrations are less than 0.03 mg/L (Figures 7-50 and 7-51).
- Almost all of the private supply wells northeast of the Site (to the east side of the Agua Fria River) and the two wells sampled to the south of the former smelter property (GW-567387 and GW-900344) have concentrations exceeding MCLs for arsenic, and in some cases, concentrations exceed 0.1 mg/L. These are areas where naturally elevated concentrations of arsenic and other metals have been detected in soil and rock outcrops (Section 7.3). These areas are not subject to groundwater transport of site-related contamination.
- Nitrate and TDS concentrations exceed primary and secondary MCLs, respectively, in supply wells in the Dewey-Humboldt area. However, aside from the area immediately north of the former Humboldt Smelter property, these exceedances are suspected to be associated with older septic systems and past agricultural activities.

11.2.5 Ambient Air

Ambient air sampled at the former Iron King Mine property had higher concentrations of arsenic than other air sample locations, indicating the tailings are a potential source of arsenic migration. Ambient air data indicate that Humboldt Smelter source areas could be a potential source of aluminum and lead migration via aerial dispersion. However, as presented in Sections 9.6.5 and 9.7.1, no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas. Concentrations of arsenic in ambient air sampled at Humboldt Proper and the former Pyrometallurgical Operations area were similar to background concentrations. Similarly, aluminum and lead were not detected or were only detected at low levels in ambient air in Humboldt Proper.

11.3 Fate and Transport

Mining and smelting activities resulted in the formation of numerous waste piles (tailings, waste rock, and ore materials) at both the former Iron King Mine and Humboldt Smelter properties, and adjacent areas. Erosion of these materials into downstream drainage resulted in deposition of tailings and impacted soils in both Galena Gulch and Chaparral Gulch. As discussed in Section 8, all of these contaminated materials are now subject to further erosion and deposition within the drainages and to surface waters, or discharge to groundwater or surface water through formation of ARD or metal leaching.

The following subsections describe the contaminant release and transport mechanisms for Iron King Mine and Humboldt Smelter sources, Chaparral Gulch, residential areas, and groundwater.

11.3.1 Iron King Mine

The primary contaminant release and transport mechanisms from the former Iron King Mine property include the following:

- Stormwater and process water were likely discharged during operation, draining under the rail trestle into the drainage along Third Street, into Chaparral Gulch, and to Galena Gulch. Operational discharges have taken place from the Iron King Mine, the former fertilizer operation, and NAI operations.
- Erosion of mine waste (primarily tailings) and transport by surface water downstream to Chaparral Gulch has occurred both during mine operation and post-operation. The sources of erosional material included tailings from the MTP, former Small Tailings Pile, and waste rock. The Small Tailings Pile has been removed and is no longer a source. However, the MTP and waste rock are subject to ongoing erosion and transport by surface water.
- Tailings impoundment failures and subsequent release and transport of tailings have resulted in the migration of tailings down Chaparral Gulch. The largest impoundment failure was in March 1964, but other smaller failures have also occurred. The MTP has not been stabilized. Stabilization of the MTP needs to be addressed in the FS.
- Contaminants have been released and transported by surface water to tributaries of Chaparral Gulch and to downstream reaches of Chaparral Gulch including the Tailings Floodplain, Lower Chaparral Gulch, and Agua Fria River.
- Erosion of mine waste and transport by surface water to Galena Gulch occurred during mine operation and post-operation. Mine waste adjacent to Galena Gulch is still subject to ongoing erosion.

- The tailings within the MTP are net acid-generating. The surface tailings (top several feet) have oxidized and produced ARD. Due to the buffering capacity of the tailings and the underlying native materials, the migration of ARD has been limited. The rate of tailings oxidation is likely limited by the rate of oxygen transport into the MTP. Sulfate, which is not strongly attenuated in soils or aquifer materials, is the primary constituent that has migrated from the MTP to shallow groundwater. Metals migration in groundwater has been minimal (see groundwater summary below).
- Aerial dispersion of ore, tailings, and mine wastes likely occurred during operations. This process has deposited metals onto surface soils surrounding the former Iron King Mine primarily to the north of the mine site.

11.3.2 Humboldt Smelter

The primary contaminant release and transport mechanisms for the Humboldt Smelter area include the following:

- Erosion of smelter and mine wastes to Chaparral Gulch and the Agua Fria River has occurred during both smelter operation and post-operation. The wastes include tailings that were disposed in the Smelter Tailings Swale, Tailings Floodplain, the Agua Fria Tailings, slag piles, and dross.
- Tailings in the Smelter Tailings Swale and Tailings Floodplain are net acid-generating and have produced ARD. However, due to the buffering capacity of the tailings and the underlying native materials, the migration of acid and dissolved metals has been limited.
- Aerial emissions from the smelter stacks during smelter operation and dust sources, both during and post-operations, likely contributed to surficial soil contamination in the area adjacent to the smelter. The aerial emissions likely included release and transport of volatile metals (primarily lead) and metal-containing dusts (primarily copper, but also other metals in smelter feed) via the smelter stacks to the smelter property and offsite downwind locations.
- Tailings within the Lower Chaparral Gulch (NR9) and the Aqua Fria Tailings Pile (NR10) contain elevated levels of COIs, and have the potential to erode into the Aqua Fria River.

11.3.3 Chaparral Gulch Tailings Migration Summary

The primary contaminant release and transport mechanisms for Chaparral Gulch include the following:

- Tailings have migrated from Iron King Mine to Chaparral Gulch along the main channel of the gulch and along the MTP 1964 Blow Out Path to Middle Chaparral Gulch and further downstream reaches.
- The Tailings Floodplain has collected tailings above the Chaparral Gulch Dam from both the Iron King Mine and Humboldt Smelter properties. These tailings have combined with alluvial material from the upper reaches of Chaparral Gulch to form the Tailings Floodplain.
- Based on evaluation of metals concentrations and ratios of metals concentrations in the MTP, the MTP 1964 Blow Out Path, Chaparral Gulch through the Middle Chaparral Gulch, and in the Tailings Floodplain, along with visual and aerial photograph analysis (Appendix C), Iron King Mine tailings have migrated to the Tailings Floodplain.
- Tailings from both the Iron King Mine and Humboldt Smelter have migrated below the dam to Lower Chaparral Gulch and the Agua Fria River.

11.3.4 Residential Areas

Factors impacting the distribution of contamination in residential areas include the following:

- Other non-site-related sources of arsenic and lead have likely resulted in increased levels at select properties. Naturally occurring arsenic (and other metals) is associated with silicic volcanic materials such as rhyolite, which are widely present within the region.
- Development of the area near the former Iron King Mine and Humboldt Smelter properties during the more than 100 years since operations began has resulted in the redistribution of contamination, resulting in a more complex patchwork distribution of metals in residential areas. Grading, cutting, and filling material within residential or commercial properties have modified the distributions of arsenic and lead caused by earlier mechanisms of surface water transport, aerial deposition, rail transport, or dumping.
- Iron King Mine waste material (such as tailings and waste rock) was historically used as fill and road base in adjacent areas, including some residential areas; smelter waste may have been used in a similar fashion.
- The historic Prescott and Eastern Railroad serviced the Iron King Mine, Humboldt Smelter, and Val Verde Smelter. Elevated arsenic and lead concentrations are present in soils along the alignment from downtown Humboldt along the Smelter Spur entering the Humboldt Smelter property. The distribution of elevated arsenic concentrations in this area is consistent with historical spills and releases of feed material for the Humboldt Smelter along the rail right-of-way and the subsequent redistribution of these materials during redevelopment of this area.
- Fill has been imported into a small number of yards from quarries with naturally elevated concentrations of arsenic. Cut-and-fill construction has occurred in areas of naturally elevated concentrations of arsenic east of the Agua Fria River and south of the former smelter property. Non-site-related sources of lead include use of leaded gasoline and lead-based paint, soldering operations, and the occurrence of residential or commercial fires. Land use has changed in some areas from historical commercial or industrial land use to residential.
- Soil in the vicinity of the former Iron King Mine and former Humboldt Smelter properties has been impacted by the deposition of windblown tailings and other wastes, as well as historical emissions and deposition of metal-rich particulates from the Humboldt Smelter stack during smelter operations.
- Residential areas along Chaparral Gulch between Highway 69 and the Tailings Floodplain have been impacted by the deposition of tailings.

11.3.5 Groundwater

The following summarizes fate and transport within groundwater:

- Groundwater encountered beneath the MTP in the shallow aquifer of the Hickey Formation has been impacted by ARD, with consistently elevated sulfate and TDS, and a predominantly calcium-sulfate chemistry that reflects these impacts. However, metals concentrations in the groundwater are low, indicating that they have been attenuated. Limited offsite migration of arsenic below the MTP has been observed.
- Deeper groundwater in the underlying Precambrian bedrock has a different chemical signature than the overlying Hickey Formation, with much lower sulfate and a predominantly sodium-bicarbonate chemistry. Although the bedrock groundwater has elevated arsenic, the data indicate that this is from natural sources.

- Activities at the former Pyrometallurgical Operations area have impacted shallow groundwater. High TDS was detected and is associated with elevated chloride and nitrate-nitrite. This was observed in the area where dross was stored and previously processed. The elevated TDS, nitrate, and chloride may be associated with releases of wastewater during dross processing, leaching of exposed dross, or a combination of these processes. Elevated TDS also has been detected in wells just north of the former Humboldt Smelter property and is related to elevated chloride and nitrate. Elevated TDS have been detected in domestic wells located north of MW-01S: GW-999947, GW 999953, GW-999966. Chloride concentrations exceed screening levels and nitrate concentrations exceed the MCL in GW-999947 and GW-999953 indicating impact from the smelter arear. Although the nitrate concentration exceeds the screening level in MW-12S (Figure 7-53), the chloride concentration is low, indicating that groundwater in MW-12S is not impacted by the Smelter. The chloride concentration in GW-999959 is also low, also indicating that it has not been impacted by the smelter. In MW-12D, nitrate is above the MCL, and chloride is slightly elevated, but below the screening level.
- Groundwater in the Chaparral Gulch Floodplain upstream of the Chaparral Gulch Dam has been impacted by ARD processes. Groundwater exceeds screening levels for arsenic, sulfate, and TDS.
- Groundwater in the saturated tailings upstream of the dam seeps beneath or around the abutments of the dam.
- Sulfate and TDS levels in groundwater wells upstream of the dam are similar to levels in surface water samples immediately downstream. Arsenic concentrations in surface water downstream of the dam are lower than the arsenic concentrations in groundwater upstream of the dam, likely due to attenuating processes.

11.4 Risk Assessment

11.4.1 Human Health Risk Assessment Summary

HHRA calculations identified exposure areas where risk levels exceed EPA risk thresholds, indicating that evaluation of actions to address human exposure pathways is necessary in the forthcoming FS for the Site. The exposure scenarios evaluated include the following (as depicted on Figure 9-1):

- Current or future residents
- Current or future occupational workers
- Intermittent recreational visitors (for example, hikers)

Chemicals of Concern. COCs were identified for each exposure area where risk was identified based on the primary risk/hazard contributors listed in Table 9-19 for the residential exposure scenario, and Table 9-20 for the occupational worker exposure scenario. The primary COCs based on the HHRA are arsenic and/or lead originating from mine- and smelter-related activities. However, some localized areas include other risk drivers (for example, 2,3,7,8-TCDD TEQ and carcinogenic PAHs at exposure area NR11 [former Pyrometallurgical Operations area]).

Residential. The great majority of yards within the APSI do not have levels of arsenic or lead that pose an unacceptable health risk. Incremental human health risks exceeding risk thresholds (ELCR greater than 10^{-4}; HI greater than 1, and/or lead greater than 400 mg/kg) for residential soil exposures were identified for 34 RYSR yards. Table 9-19 provides a summary of the exposure areas, indicates which EPA risk threshold is exceeded, and lists the primary risk contributors for each property.

Figure 11-1 shows those current residential exposure areas identified with risk estimates exceeding any of the EPA risk thresholds (that is, where the ELCR is greater than 1 x 10^{-4}; the HI is greater than 1; and/or the lead EPC is greater than 400 mg/kg) for potential exposure to soil for the residential exposure scenario. Figure 11-2 provides more detail by combining the risk-related information listed below.

- Yards or properties with an incremental ELCR greater than 1 x 10^{-4} or less than 1 x 10^{-4}
- Yards or properties with an incremental HI greater than 1 or less than 1
- Lead and arsenic EPCs for yards or properties
- Highlights showing yards exceeding risk thresholds (ELCR greater than 10^{-4}; HI greater than 1, and/or lead greater than 400 mg/kg)

Incremental human health risks exceeding risk thresholds for residential soil exposures were also identified for the stormwater diversion berm identified as a hot spot within exposure area RSAR-D and for exposure area NR19, which may have future residential land uses. Remaining residential soil exposures in RSAR areas can be excluded from further evaluation because no unacceptable incremental human health risks were identified.

Occupational. Incremental human health risks exceeding risk thresholds (ELCR greater than 10^{-4}; HI greater than 1, and/or lead greater than 800 mg/kg) for occupational worker soil exposures were identified for the following areas (shown on Figure 11-3):

- NR4 JT Septic Facility
- NR5 MTP 1964 Blow Out Path
- NR8 Tailings Floodplain
- NR9 Lower Chaparral Gulch
- NR10 Agua Fria Tailings Pile
- NR11 Former Pyrometallurgical Operations Area
- NR12 Smelter Plateau
- NR14 South of Former Iron King Mine Property
- NR16 Former Mineworks Area
- NR17 MTP
- NR18 NAI Operations Area

Recreational. No unacceptable human health risks were identified for recreational surface water and sediment exposures within the Agua Fria River. Similarly, the incremental recreational visitor ELCR estimates for soil do not exceed the EPA target risk range of 1 x 10^{-6} to 1 x 10^{-4}, and the incremental HIs do not exceed the EPA threshold value of 1 at any of the 20 exposure areas that are currently non-residential properties. The assessment of risks from exposure to lead in soil for the recreational visitor scenario was evaluated under the residential exposure scenario.

Ambient Air. Ambient air sampled at the former Iron King Mine property had higher concentrations of arsenic than other air sample locations, and HI estimates slightly exceeded the EPA HI threshold value of 1 (HI was 2 at Stations AIK-01 and AIK-01A; see Figure 7-56). These results indicate that the highest risks and hazards from ambient air are in the immediate vicinity of the MTP. Concentrations of arsenic in ambient air sampled at Humboldt Proper and the former Pyrometallurgical Operations area were similar to background concentrations, and no residential health risks exceeding the EPA risk thresholds were identified for any of the ambient air monitoring stations near current residential areas.

11.4.2 Ecological Risk Assessment

The ERA was performed to provide an analysis of the potential for adverse effects on ecological resources associated with the Site. The ERA identified and characterized the toxicity of COPECs, the potential exposure pathways, the potential ecological receptors, and the likelihood of adverse ecological effects under current and reasonably anticipated future land and water use conditions. The ERA followed the tiered approach recommended by EPA (Figure 10-1) in that both a SLERA (Tier 1) and a BERA (Tier 2) were performed. Potentially complete ecological exposure pathways at the Site are depicted on Figure 10-2 and include the following:

- Potential exposure of soil invertebrates and terrestrial plants to site-related constituents present in soil
- Potential exposure of terrestrial wildlife (birds and mammals) through ingestion of site-related constituents in soil, terrestrial forage, and/or prey items
- Potential exposure of aquatic and benthic resources within the Agua Fria River (aquatic plants, benthic and water column invertebrates, and fish) to site-related constituents present in sediment or surface water
- Potential exposure of semi-aquatic wildlife (birds and mammals) through ingestion of site-related constituents in sediment, aquatic forage/prey, and surface water

Because the Site covers a large geographic area, it was divided into numerous ecological exposure areas, as depicted on Figures 10-3 and 11-4. The BERA indicated that there is a potential for adverse risk to ecological receptors from selected metals detected in soil, sediment, and surface water at the Site. These metals are recommended for risk management consideration and evaluation of actions to address the associated ecological exposure pathways in the forthcoming FS for the Site.

11.4.2.1 Terrestrial Ecological Exposures to Soil

Figure 11-4 provides a summary of the estimated ecological risks for potential exposure to soil at the 33 identified terrestrial exposure areas. Based on the results of the BERA for terrestrial exposure pathways, COECs potentially posing risk were identified for soil at 15 of the 33 terrestrial exposure areas evaluated (see Table 10-9). The COECs include antimony, arsenic, cadmium, copper, lead, selenium, zinc, and dioxins/furans. Of these, the most prevalent COECs are arsenic (at 11 of the 33 exposure areas evaluated) and lead (at 15 of the 33 exposure areas evaluated). Dioxins/furans were identified as a COEC at NR11 (former Pyrometallurgical Operations area) and NR12 (Smelter Plateau).

11.4.2.2 Ecological Exposures to Agua Fria Sediment

Sediment concentrations were found in localized hot spots at levels potentially posing ecological risk at all three of the Agua Fria River exposure areas evaluated (see Table 10-9), with the highest potential risks in the Agua Fria River occurring in exposure area AF-02. The COECs include arsenic, cadmium, chromium, copper, lead, nickel, zinc, and dioxins/furans (see Figures 10-8 for arsenic, 10-9 for copper, and 10-10 for lead). Dioxins/furans were identified as a COEC in exposure area AF-01.

Sediment samples collected upstream of the smelter at AF-01 (BKG locations), along with the soil background data (Appendix E), indicate there are naturally occurring sources of COIs, in particular arsenic and copper, at concentrations that are contributing to the ecological risk. In exposure area AF-02, the stretch of the Agua Fria River between locations OW-20 and AF-5 runs along the eastern boundary of NR11 (the former Pyrometallurgical Operations area). These samples were collected in an area where EPA observations indicate dross mixed with slag extends down to the Agua Fria River. In exposure area AF-03, location AF-12 is a localized hot spot just downstream of the confluence with Chaparral Gulch. This location was resampled during a subsequent field effort, and concentrations were lower by an order of magnitude in the resample, indicating that impacts to this stretch of the Agua Fria River are localized, the sediment material in this area is transient (moves in response to increases in flow), or a combination of both factors (EA, 2010).

11.4.2.3 Ecological Exposures to Agua Fria River Surface Water

Surface water concentrations were found at levels potentially posing ecological risk at all three of the Agua Fria River exposure areas evaluated. Potential risks exist for aquatic organisms (for example, aquatic plants, water column invertebrates, and/or fish) (see Table 10-9). Risks were not calculated for birds or mammals drinking surface water. Some of the constituents measured in surface water could be contributed by the naturally mineralized conditions prevalent in the region or wastewater discharges upstream of the Site, rather than specifically from mine- or smelter-related sources. Most of the flow in the Agua Fria River upstream of the Site consists of effluent from the Prescott Valley Wastewater Treatment Plant, except possibly during higher-flow storm events.

11.4.2.4 Areas with No Unacceptable Risk

No unacceptable human or ecological health risks were identified for soil or terrestrial exposures for the exposure areas listed below. Figures 6-3 and 10-3 show the location of these areas.

- NR2 Humboldt Elementary School / Dewey-Humboldt Town Hall
- NR3 Upper Chaparral Gulch
- NR15 Auto Yard
- NR20 North of Chaparral Gulch
- NE-02, NE-04, NE-06, NE-08, NE-09, and NE-11
- NW-01, NW-03
- RSAR-A, RSAR-B, RSAR-C, RSAR-D (excluding hot spot), RSAR-E, RSAR-F, RSAR-G, and RSAR-H
- SE-01 and SE-02
- 3001

11.5 Conclusions and Recommendations

The evaluations documented in this RI Report have provided an understanding of the physical characteristics of the Site, the nature and extent of associated contamination, how and why the contamination was distributed and may continue to migrate if not addressed, and the potential human health and ecological risks associated with the remaining contamination. This section provides primary conclusions regarding development of remedial alternatives during preparation of the FS.

11.5.1 Conclusions

The Site has been sufficiently characterized and the areas of contamination have been adequately identified, investigated, and assessed to proceed with identification and evaluation of remedial alternatives. Preliminary calculations of the volume, depth, and areal extent of source areas and contaminated material, presented in Tables 7-24 and 7-25; will require further evaluation during the FS.

Primary considerations pertaining to the development of remedial alternatives at the former Iron King Mine property include the following:

- Potential for additional slope failures at the MTP and migration of contaminated tailings
- Continued erosion of tailings, waste rock, and contaminated soils to Chaparral Gulch and Galena Gulch
- Potential for an increase in the generation of ARD and subsequent migration of sulfate, metals, and acid from the MTP to groundwater and surface water

- Potential for human and ecological contact with tailings, waste rock, and contaminated soil in former Iron King Mine source areas (MTP, former Mineworks area, and NAI Operations area) and areas north and south of the MTP
- Potential for dust generation and aerial suspension of tailings and fine-grained contaminated soils at the mine property during high-wind events (It is noted that no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas.)

Primary considerations for development of remedial alternatives at the former Humboldt Smelter property, Chaparral Gulch, and the Agua Fria River include the following:

- Continued erosion of tailings from the Smelter Tailings Swale to the Tailings Floodplain and Lower Chaparral Gulch
- Potential for large-scale erosion of tailings and contaminated soil from Chaparral Gulch and the Tailings Floodplain to lower reaches of Chaparral Gulch and the Agua Fria River
- Potential failure of Chaparral Gulch Dam and discharge of contaminated soil, tailings, and groundwater to the Agua Fria River
- Potential for human and ecological contact with tailings, dross, slag, and contaminated soil and sediment within Chaparral Gulch depositional areas and Humboldt Smelter source areas
- Potential for ecological health risk from exposure to surface water and sediment in the Agua Fria River that is currently impacted by Humboldt Smelter source areas, the Agua Fria Tailings Pile, and discharges from Chaparral Gulch
- Potential for an increase in the generation of ARD and subsequent migration of sulfate, metals, and acid from the Tailings Floodplain to groundwater and surface water
- Potential for dust generation and aerial suspension of dross, tailings, and fine-grained contaminated soil at the smelter property during high-wind events (It is noted that no unacceptable residential health risks were identified for any of the ambient air monitoring stations near current residential areas.)

Primary conclusions pertaining to development of remedial alternatives for the residential areas include the following:

- More than 92 percent of the yards within the APSI do not have levels of arsenic or lead that pose a health risk. Incremental human health risks exceeding risk thresholds (ELCR greater than 10^{-4}; HI greater than 1, and/or lead EPA greater than 400 mg/kg) for residential soil exposures were identified for 34 RYSR yards (see Figures 11-1 and 11-2). The impacted yards should be evaluated during the planned FS. Many of these yards are located north of the former Humboldt Smelter property in Humboldt Proper, along the historic Smelter Spur, and along areas of tailings deposition in Chaparral Gulch.
- At the Humboldt Elementary School, soil metal concentrations were below screening levels and no unacceptable risks were identified in soil or ambient air.
- Incremental human health risks exceeding risk thresholds for residential soil exposures were identified related to a stormwater diversion berm, as a hot spot within exposure area RSAR-D, and in exposure area NR19, which may have future residential land uses.
- Hot spots from combined site-related and non-site-related sources of arsenic and lead result in risks above EPA risk management thresholds in select yards.
- Remediation or institutional controls may be required to prevent exposure to sources areas resulting from changes in land use.

- Potential for ecological health risks exists at some of the residential and off-property commercial areas where human health risks exceed risk thresholds (see Figure 11-4).

11.5.2 Data Limitations and Recommendations for Future Work

Recommendations for additional evaluations that should be considered during the FS or remedial design phases of the project are summarized below.

- **Source Material Volume Estimates.** Volume estimates of tailings and impacted material were developed during Phase 1 of the RI (EA, 2010). These should be re-estimated incorporating additional data collected during the subsequent phases of the investigations. Volumes should be estimated for each exposure area and material type to assist in development of alternatives.
- **Remedial Design Tools.** The geospatial tools used for preparation of the RI Report included Esri, ArcGIS, and Rockworks software. Although those software packages are suitable for visualization and analysis of subsurface data for development of an RI, 3-D design software such as MicroStation, AutoCAD, and Inroads should be used for design and development of alternatives. Digital terrain models should be developed, and all geospatial data referenced to onsite survey controls and monuments.
- **MTP Stability Analysis.** Stability of the MTP should be evaluated considering both slope stability and liquefaction potential.
- **Monitoring Wells.** Groundwater testing and measuring of water levels at the EPA monitoring wells should be conducted routinely.
- **Chaparral Gulch Dam Stability Analysis.** Structural stability of the dam should be evaluated and conformance with dam safety requirements addressed.
- **Slag Movement.** Stability of the slag pile should be evaluated, particularly with respect to the large cracks in the primary slag pile. Monitoring of the cracks should continue.
- **Brown Clay.** The extent and thickness of the Brown Clay in Chaparral Gulch and the Smelter Tailings Swale should be evaluated as a potential liner material.
- **Acid Rock Drainage.** Field testing to determine infiltration rates through waste materials, recharge rate to groundwater, and geochemical properties of the natural solids would assist in determining the potential for ARD migration.
- **Groundwater.** Groundwater in the vicinity of the former Humboldt Smelter property is locally impacted by chloride, nitrate, and TDS; exceedances may be related to releases of wastewater associated with dross processing, leaching of exposed dross, or a combination of these processes. The extent of site-related impacts to chloride, nitrate, and TDS concentrations north of the former Humboldt Smelter property is not well defined, as nitrate and TDS concentrations in the Town of Dewey-Humboldt are also impacted by non-site-related sources, including older septic systems and past agricultural activities.
- **Groundwater Modeling.** Groundwater modeling should be considered to better understand groundwater flow and potential migration of contaminants at both the former Humboldt Smelter property and the former Iron King Mine property.
- **Surface Water.** Storm event surface water samples should be collected upstream of the Humboldt Smelter property to quantify potential upstream sources of contamination from cropland, urban runoff, or other non-site-related sources.

- **Completed Removal Actions.** Coordinate data pertaining to removal actions and confirmation sampling should be incorporated into the site dataset. Removal action data should be reviewed to determine if additional remedial actions or land use restrictions are warranted.
- **Land Use and Stakeholder Considerations.** Possible future land uses are included in the Town of Dewey-Humboldt General Plan (2009) and the EPA reuse assessment (E2 Inc., 2010). The FS should include a detailed evaluation of future land use, incorporating the results of the RI.

SECTION 12

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