



**FINAL REMEDIAL  
INVESTIGATION REPORT  
KLONDYKE TAILINGS WQARF SITE  
KLONDYKE, ARIZONA**

*Prepared for:*  
**ARIZONA DEPARTMENT OF  
ENVIRONMENTAL QUALITY**

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| LIST OF ACRONYMS |  |
|------------------|--|
| ADEQ             | Arizona Department of Environmental Quality                          |
| ADHS             | Arizona Department of Health Services                                |
| ADWR             | Arizona Department of Water Resources                                |
| ABA              | Acid-Base Accounting   |
| AGFD             | Arizona Game and Fish Department                                     |
| AgL              | Agricultural Livestock   |
| AGP              | Acid Generation Potential  |
| ANP              | Acid Neutralizing Potential  |
| ARD              | Acid Rock Drainage   |
| ASU              | Arizona State University   |
| ATSDR            | Agency of Toxic Substances and Disease Registry                      |
| ATV              | All-Terrain Vehicle  |
| AWQS             | Aquifer Water Quality Standards                                      |
| BLM              | U.S. Bureau of Land Management                                       |
| bgs              | Below Ground Surface   |
| CAB              | Community Advisory Board   |
| CC&N             | Certificate of Convenience and Necessity                             |
| CERCLA           | Comprehensive Environmental Response, Compensation and Liability Act |
| CFR              | Code of Federal Regulations  |
| CIA              | Community Involvement Area   |
| CIP              | Community Involvement Plan   |
| COC              | Chain Of Custody   |
| COPCs            | Contaminants of Potential Concern                                    |
| cfs              | Cubic Feet per Second  |
| DWS              | Domestic Water Source  |
| EDXRF            | Energy-Dispersive X-Ray Fluorescence                                 |
| EPA              | U.S. Environmental Protection Agency                                 |
| ERA              | Early Response Action  |
| ESA              | Endangered Species Act   |
| °F               | Degrees Fahrenheit   |
| FBC              | Full Body Contact  |
| FC               | Fish Consumption   |
| ft               | Feet   |
| GPL              | Groundwater Protection Level   |
| gpm              | Gallons per Minute   |
| GPS              | Global Positioning System  |
| ICP              | Inductively Coupled Plasma   |
| IDW              | Investigation Derived Waste  |
| mg/kg            | Milligrams Per Kilogram  |
| mS/m             | MilliSiemens per Meter   |
| µg/L             | Micrograms per Liter   |
| NAWQC            | National Ambient Water Quality Criteria                              |
| NR-SRL           | Non-Residential Soil Remediation Level                               |



| <b>LIST OF ACRONYMS</b> |  |
|-------------------------|--|
| PA/SI                   | Preliminary Assessment/Site Inspection |
| ‰                       | Parts per Thousand                     |
| PPE                     | Personal Protective Equipment          |
| QAPP                    | Quality Assurance Project Plan         |
| QA                      | Quality assurance                      |
| QC                      | Quality control                        |
| RI                      | Remedial Investigation                 |
| RPD                     | Relative Percent Difference            |
| R-SRL                   | Residential Soil Remediation Level     |
| UofA                    | University of Arizona                  |
| USACE                   | U.S. Army Corps of Engineers           |
| USFWS                   | U.S. Fish and Wildlife Service         |
| USGS                    | U.S. Geologic Survey                   |
| WQARF                   | Water Quality Assurance Revolving Fund |



## **1.0 EXECUTIVE SUMMARY**

URS Corporation (URS) was retained by the Arizona Department of Environmental Quality (ADEQ) to conduct a Site Remedial Investigation (RI) at the Klondyke Tailings Water Quality Assurance Revolving Fund (WQARF) Site (Site). The purpose of this task was to evaluate the nature and extent of heavy metal contamination in soil, sediment, groundwater and surface water at and in the vicinity of the Site and to characterize the potential risk to human health and the environment. The area to be studied as part of this project includes the Upper and Lower Tailings Piles and processing area, adjacent properties, a portion of the 100-year floodplain and channel of Aravaipa Creek, and a portion of Laurel Creek adjacent to the Site. Tailings and soil samples were tested to evaluate the nature and extent of the source of metals contamination. Streambed sediment samples also were analyzed to help characterize the contaminant migration pathways. Domestic wells in the vicinity of the Site were also sampled to evaluate groundwater conditions adjacent to, up gradient, and down gradient of the Site.

Previous soil investigations identified the heavy metals: arsenic, antimony, cadmium, copper, manganese and lead as the contaminants of concern in the tailings piles and surrounding soil. Those metals are present at concentrations exceeding the Residential Soil Remediation Levels (R-SRLs) and minimum Groundwater Protection Levels (GPLs). The Upper and Lower Tailings Piles were identified as the primary contaminant sources. However, a secondary source of heavy metal contaminants was identified during these site characterization activities, the mineralized rock in Laurel Canyon upstream from the Site, including mine tailings and waste rock located near the abandoned Grand Reef Mine.

A Conceptual Site Model (CSM) was developed to evaluate the migration pathways and exposure potential for the contaminants of concern from the source to human and ecological receptors. Physical migration pathways included surface water migration during storm water runoff from the tailings piles and surrounding impacted soil, and airborne migration during wind erosion and dust-generating activities, which would mobilize and transport contaminants. The potential for chemical migration of contaminants was verified by testing of tailings and soil for metal leaching from tailings material. The results indicated there is potential for metal contaminants to mobilize in the tailings piles. Once mobilized, metal ions can be transported by chemical processes such as ion-exchange or sorption between migrating fluids and soil or migrating/infiltrating fluids and soil pore water. The most likely mode of chemical migration is during a strong storm event where storm water runoff could pick up metal ions from tailings piles, transport the contaminants offsite, and release the metal ions during an exchange with soil or other fluid. Groundwater was not identified as a migration pathway. Human receptors include residents that live on adjacent properties where soil contamination is present. Ecological receptors include aquatic animal species such as fish and



amphibians; and various terrestrial, mammal, bird, and reptile species that come in contact with contaminated surface water or stream sediments. Bioavailability testing for lead and arsenic indicated that these compounds are readily bioavailable in both the tailings and in soil samples collected from the former production area.

Aravaipa Creek's 17 mile long perennial flow stretch is considered by the Arizona Game and Fish Department to have the best remaining assemblage of desert fishes in Arizona. The stretch is home to seven native species including three federally-listed endangered species; the Spikedace, Loach Minnow, and the Gila Topminnow. In addition, Aravaipa Creek is a unique water under Arizona Administrative Code, R18-11-112. The Site lies approximately four miles upstream of the Nature Conservancy's Aravaipa Canyon Preserve and approximately six miles upstream of the Bureau of Land Management's Aravaipa Canyon Wilderness.

Extensive soil, tailings and sediment sampling was conducted at and in the vicinity of the Site in 2006 and 2007. Soil samples were collected at the surface (0 to 3 inches), 6 inches, 12 inches, and 24 inches below ground surface. A total of 2,406 soil and tailings samples, including 215 duplicate samples, were collected and analyzed by energy dispersive X-ray fluorescence (EDXRF) to screen for lead and nine other metals. Additionally, 330 of the collected samples were submitted to a fixed-base laboratory and analyzed for up to 11 total metals by U.S. Environmental Protection Agency (EPA) Method 6010B. A total of 75 stream sediment samples, including 4 duplicate samples, were collected from Aravaipa and Laurel Creeks and analyzed for lead and nine other metals by EDXRF. To investigate the subsurface soil conditions at the Site, nine soil borings were advanced and 30 subsurface soil samples, including 3 duplicate samples, were collected at 1, 5, and 10 feet (ft) below ground surface. Those subsurface samples were analyzed for 10 total metals by EPA Methods 6010B and 7471A, and cyanide by EPA Method SM4500-CN C, E.

Field screening (i.e., EDXRF) results for metals in soil samples were evaluated by comparing observed concentrations with R-SRLs. Exceedances of the R-SRL were reported for antimony, arsenic, cadmium, copper, lead, manganese, mercury, and zinc at the surface and depths of 6 inches at sampling locations at and in the vicinity of the Site. At depths of 12 inches those same metals, except for copper, were reported exceeding the R-SRL. At depths of 24 inches only antimony, arsenic, lead and mercury were reported exceeding the R-SRL. Lead is the most prevalent contaminant in the samples analyzed.

Arsenic is commonly associated with lead in the Klondyke tailings, and elevated concentrations of arsenic were reported in soil. However, the EDXRF results indicated raised detection limits or elevated concentrations for arsenic whenever lead concentrations were shown in the sampled locations. The elevated detection limits were typically an order of magnitude less than the



corresponding detected lead concentration. Further investigation on the cause of this occurrence indicates that the EDXRF Spectrometer utilized at the time of the investigation had limitations in analyzing for arsenic when lead is present. Lead x-rays (from EDXRF) produce two strong spectral peaks at energies 10.5 and 12.6 keV. The most intense arsenic spectral peak is also at 10.5 keV and is therefore strongly affected by the presence of lead in the sample. Thus, the presence of lead in a sample elevates the arsenic detection level. Based on these findings, the majority of the EDXRF arsenic results are considered invalid and unusable, with the exception of when arsenic was shown to be <10 milligram per kilogram (mg/kg).

Fixed-base analyses of 330 soil samples for metals in soil samples were compared with R-SRLs. Arsenic and lead concentrations exceeded the R-SRL in samples collected at the surface and 6 inches depth. At 12 inches depth arsenic, cadmium, lead and zinc were reported at concentrations exceeding the R-SRL. At 24 inches depth only lead was reported at concentrations exceeding the R-SRL. The fixed-base laboratory results confirmed that lead is the driver analyte for remedial action.

Stream sediment samples collected from Aravaipa Creek and Laurel Creek were field screened for metals. None of the nine metals analyzed was detected at concentrations exceeding the corresponding R-SRL. Fixed-base analyses of four stream sediment samples reported arsenic exceeding the R-SRL in three samples and lead exceeding the R-SRL in two samples.

A statistical analysis was performed on soil data to compare cadmium, lead, and manganese results by the EDXRF screening method to their respective results by the fixed-base EPA Method 6010B. The analysis confirmed that EDXRF results for cadmium, lead, and manganese are statistically correlated to their respective 6010B results and EDXRF results are generally conservatively greater than 6010B results. This means that, with the exception of arsenic results, EDXRF results can be used to guide remedial action at the Site, with confirmation sampling used to verify that the excavation remediation is effective, and verification sampling used to confirm the correlation remains statistically significant. A statistical analysis comparing the EDXRF and fixed-base 6010B results for arsenic was not performed due to the lead interference issues associated with the EDXRF Spectrometer used at the time of inspection. However, direct comparison of EDXRF and 6010B results for arsenic indicates that in all instances where EDXRF registered <10 mg/kg, the corresponding 6010B results were also below detection limits.

The EDXRF soil analytical results for lead were plotted on maps to show the lateral extent of contamination at and in the vicinity of the Site. In addition, the vertical extent of contamination was shown on maps for three sampling depths: 6 inches, 12 inches and 24 inches. The maps show elevated concentrations of lead at and adjacent to the Site, including high concentrations of heavy metals at a small historical mill site on the property east of the Site. In addition, lead contamination



is present on the Laurel Creek alluvial fan that extends southwestward out of Laurel Canyon. These results suggest there are two sources of lead contamination: the Upper and Lower Tailings Piles; and mineralized rock in Laurel Canyon up gradient from the Site, including waste rock/tailings at and near the Grand Reef Mine. In addition, the limited EDXRF and Method 6010 soil analytical results for arsenic were also plotted on maps, which showed the lateral and vertical extent of contamination at and in the vicinity of the Site was similar to that of lead. These results are important to consider when planning and implementing remedial action at the Site and on adjacent properties under the WQARF program.

In July 2001, fifteen private domestic wells in the Klondyke area were sampled. No drinking water standards were exceeded in any of the wells tested. Results indicated very good water quality with respect to metals.

Aquifer conditions were also evaluated at the Site by collecting quarterly groundwater samples at depths of approximately 75 feet below ground surface from four monitor wells. No metals were detected at concentrations exceeding the corresponding Aquifer Water Quality Standards (AWQS), where established. The aquifer is the primary source for domestic water in Aravaipa Valley. These results suggest that, under normal conditions, groundwater is not a pathway for contaminant migration and exposure.

The lateral extent of lead contamination found in surface soils during this investigation was greater than expected. The sample results indicated the potential for a larger area of contamination from historic milling activities, windblown or surface water movement of metals contamination as well as other sources of metal contamination may exist in the vicinity of the Site such as the Grand Reef Mine, Dogwater Mine, and tailings on parcel 110-47-006. A possible explanation of the extensiveness of the lead contamination could be the presence of the Grand Reef Mine and Dogwater Mine upstream in Laurel Canyon. Lead and arsenic contamination is present on the Laurel Creek alluvial fan that extends southwestward out of Laurel Canyon. These results indicate that there are three sources of lead and arsenic contamination: the Upper and Lower Tailings Piles; mineralized rock in Laurel Canyon up gradient from the Site, including waste rock/tailings at and near the abandoned Grand Reef Mine and Dogwater Mine; and tailing material located on the hillside of parcel 110-47-006, believed to have been a historical attempt at processing ore from the Dogwater Mine.

The original WQARF Site boundaries were placed around the two source area parcels, 110-47-003g and 110-47-003h. Since completing the Site Characterization Report, the Site boundaries have been expanded to encompass residential parcels and reaches of Laurel Creek that have elevated concentrations of lead.



## **2.0 INTRODUCTION**

URS Corporation (URS) has been retained by the Arizona Department of Environmental Quality (ADEQ) to conduct a Remedial Investigation (RI) at the Klondyke Tailings Site (Site) under the authority of the ADEQ Water Quality Assurance Revolving Fund (WQARF).

### **2.1 PURPOSE OF REPORT**

The purpose of this RI is to evaluate the nature and extent of metal contamination in soil, sediment, groundwater and surface water at and in the vicinity of the Site and to characterize the potential risk to human health and the environment. The results of the RI will be used to develop strategies for timely and cost-effective remediation of metals contamination at and in the vicinity of the Site.

### **2.2 SITE BACKGROUND**

The Klondyke Tailings WQARF Site is a 10-acre parcel of private property located 1.2 miles north of the town of Klondyke, Graham County, Arizona (Figure 1). The Site is located 4.5 miles upstream of the Aravaipa Canyon Wilderness Area managed by the U.S. Bureau of Land Management (BLM). The Nature Conservancy's Aravaipa Canyon Preserve is located immediately upstream of the wilderness area. The Site is located in the east ½ of the southwest ¼ of Section 6, Township 7 South, Range 20 East of the Gila and Salt River Baseline and Meridian.

### **2.3 LIMITS OF STUDY AREA**

The study area boundaries are shown in Figure 2 and can be placed where concentrations of lead are encountered above the R-SRL of 400 mg/kg. As shown on Figure 5, the northern boundary of the site can be placed along the current extent of lead contamination, which is beyond the original WQARF site boundary composed of source area parcels 110-47-003g and 110-47-003h. The northern boundary of the Site can be placed along the northern portion of the Laurel Creek alluvial fan, approximately on a line between grid points 3200N-500E and 2300N-2700W, from the Laurel Creek channel to the Aravaipa Creek channel. Similarly, the eastern end of the study area can be placed at the base of the slope of the low hills that bound the eastern edge of the Aravaipa Creek floodplain. The elevated metals on the low hill north of the property east of the Site, parcel 110-47-006, resulted from historical milling operations conducted in that area of the parcel. Due to site access restrictions, the adjacent property east of the Site situated south of 800N and east of 0W, located in parcel 110-47-004 could not be sampled (Figure 2).

The original Site boundaries were placed around the two source area parcels, 110-47-003g and 110-47-003h. Since completing the SCR, the Site boundaries have been expanded to encompass



residential parcels and reaches of Laurel Creek that have elevated concentrations of lead. Parcels located in the WQARF Site boundary are illustrated in Figure 2 and include:

- 110-47-001b
- 110-47-001g
- 110-47-001h
- 110-47-001i
- 110-47-001k
- 110-47-001m
- 110-47-003b
- 110-47-003d
- 110-47-003f
- 110-47-003g
- 110-47-003h
- 110-47-006

## **2.4 SITE DESCRIPTION**

The Site is the former location of a flotation mill that processed ore material mined from several lead, zinc, copper, silver and gold mines that operated in the Santa Teresa Mountains north and northeast of the Site from the late 1870s through the 1960s. Metal ore was processed by a series of flotation mills at the Site, resulting in two tailings piles. The Upper Tailings Pile is located approximately 30 feet from the bank of Aravaipa Creek, contains approximately 33,000 cubic yards of material, and is 7 to 16 feet high. There has been some erosion of tailings on the western and southern edges of the Upper Tailings Pile into Aravaipa Creek. The Lower Tailings Pile is approximately 200 feet downstream of the Upper Tailings Pile. This pile is 60 to 75 feet east of the bank of Aravaipa Creek, contains approximately 36,000 cubic yards of material, and is up to 23 feet high. Although the surface of the Lower Tailings Pile is fairly compacted, there has been some erosion at the northwest corner of the pile into a narrow dry wash that flows parallel to the west edge of the tailings pile (ADEQ, 2007).

Remnants of the mill processing facilities are located between the two tailings piles, designated as the processing area. There are several structures from the mill remaining at the Site, but they are in very poor condition and a few have collapsed since 1999. Two structures, a barn and a storage building, postdate the closure of the mill in 1957. The Site is described in detail in an archaeological and cultural resources report provided in (URS, 2004a).

## **2.5 SITE HISTORY**

In approximately 1948, Athletic Mining Company constructed a flotation processing mill next to Aravaipa Creek, which operated until about 1958. During its time of operation, lead, zinc, and copper concentrates were produced, along with two mine waste tailings piles of approximately



69,000 cubic yards. Other operators may have contributed to the piles prior to and after the Athletic Mining Company. Table 1 includes a description of the features left at the Athletic Mining Site.

The tailings piles left behind after the 1958 closure of the mine are located close to Aravaipa Creek and erosion of the piles has occurred. The Upper Tailings Pile, located 30 feet from the bank of Aravaipa Creek, is seven to 16 feet high and contains approximately 33,000 cubic yards of material. The Lower Tailings Pile is located 200 feet downstream of the Upper Tailings Pile and 60 to 75 feet from the bank of Aravaipa Creek and contains approximately 36,000 cubic yards of material.

## **2.6 OPERATIONAL HISTORY**

At the request of ADEQ, HdyroGeoLogic, Inc. (HGL) prepared a report summarizing the operational history of the Site. The following describes HGL's findings (HGL, 2012).

The Klondyke Mill was located in the Aravaipa Mining District (Aravaipa District), the largest of three lead-producing mining districts in Graham County, Arizona, and the only zinc-producing mining district in the county. Although mining occurred in the Aravaipa District beginning in the mid-1870s, the earliest known aerial photograph of the Klondyke Mill site, taken in 1937, shows no distinguishable mill or tailings piles at or in proximity to the site. It was not until the third period of intense mining in the Aravaipa District, beginning during World War II, that the Klondyke Mill started operating.

### **2.6.1 Athletic Mining and Smelting Company / Athletic Mining Company Operations**

In response to increased demand for lead and zinc during World War II, and spurred by federal subsidies, the Athletic Mining and Smelting Company of Fort Smith, Arkansas, expanded its operations to Klondyke, Arizona. In January 1942, Athletic Mining and Smelting Company leased mining claims near Klondyke from the Aravaipa Mining Corporation. The lease included an option to buy patented lode claims in the Aravaipa District, and in April 1942 the Athletic Mining and Smelting Company exercised that option. After purchasing the claims, the Athletic Mining and Smelting Company focused mining operations at the Head Center and Iron Cap Mines, the two largest lead and zinc producing mines in the region. As a result, the Athletic Mining and Smelting Company became the largest producer of lead and zinc in the Aravaipa District. However, the Aravaipa District contributed only about 1 percent to the overall statewide production of lead and zinc during World War II.

In December 1943, Athletic Mining Company, Inc. (Athletic Mining Company) incorporated in the state of Arizona. Under conditions of a lease, the Athletic Mining Company purchased property for the Klondyke Mill in 1947 from the Aravaipa Leasing Company [KTDEQP 1907]. The mill site was



located 3 miles west of the town of Klondyke. The Athletic Mining Company also acquired equipment for the Klondyke Mill from Aravaipa Leasing Company. The equipment had been used at an old flotation mill located near the Grand Reef Mine.

Several sources indicate that the Klondyke Mill had been constructed by 1948, although one former mill employee recalled that the mill had existed in 1944, when the property was still being leased by Athletic Mining Company. A few sources suggest that the Klondyke Mill may have been rebuilt in 1948 to increase processing capacity. As with the date of construction, the exact date for the start of operations at the Klondyke Mill is unclear. According to some sources, mill operations were anticipated to begin in late November 1947; however, other sources refer to the mill as nonoperational in March 1948. By sometime in 1948, the Klondyke Mill was operational, with a capacity to process 100 tons of ore per day.

The Klondyke Mill was a flotation mill that included a crusher, a conveyance system to move the crushed ore to storage tanks, and one building that housed the ball mill, concentrator tanks, flotation cells, diesel engines, and a laboratory. Other buildings included a mechanic's shop and storage shed. Approximately 11 homes were built north of the processing area to house mill employees.

During the milling process, the ore was first crushed to the size of gravel. The crushed ore was either stored in tanks to await further processing or conveyed directly to the ball mill for grinding. The crushed ore was mixed with water, and the resulting slurry was ground by iron balls approximately 9 inches in diameter in the ball mill, further reducing the size of the ore. The fine-grained ore was conveyed through four flotation cells where chemical reagents were used to separate and float ore to the top of the tank, where it could be scraped off with paddles. Different reagents were added to recover specific base metals. Chemical reagents used in lead and zinc flotation mills included cyanide, lime, zinc sulfate, copper sulfate, and "Aerofloat" or "Aerofloc." Zinc and lead were the primary metals recovered, but some copper, silver, and gold were also extracted. Once the metal concentrates had been scraped off the top of the flotation cells, they were transferred to metal bins, filtered, and trucked to the railroad.

Water used during the milling process was provided by a large well located at the mill site. The water was pumped from the well to a large storage tank. Sludge and wastewater from the flotation process was pumped out through a pipe and discharged into a 10- to 12-foot deep tailings settling and evaporation pond adjacent to the mill. The flotation chemicals were reportedly neutralized with reagents prior to discharge. According to one source, the Klondyke tailings pile was never re-treated.

By 1952, the Klondyke Mill had been rebuilt to increase capacity and was operating at full capacity, processing 120 tons of ore per day. The ore processed was primarily lead and zinc, with a small amount of copper. In 1954 and 1955, the mill was running 3 shifts per day, 5 days per week, and was



processing 100 tons of ore per day. Milling operations recovered lead, zinc, and a smaller amount of copper.

The Athletic Mining Company had purchased claims for several mines, but the two mines that contributed ore to the Klondyke Mill were the Head Center and Iron Cap Mines. The Head Center Mine was the larger producer of the two mines. The majority of the lower grade ore from the Iron Cap Mine was processed at the Klondyke Mill. Lead ore and concentrates were shipped to a smelting facility in El Paso, Texas; zinc ore and concentrates were shipped to Athletic Mining and Smelting Company's Fort Smith, Arkansas, facility. The Athletic Mining Company operated the Aravaipa Mines and the Klondyke Mill until 1957, at which point the declining prices for nonferrous metals made continuing operations too costly and, as a result, the mill was closed.

### **2.6.2 American Zinc, Lead, and Smelting Company**

In 1963, the Klondyke Mill was reopened under the ownership of the American Zinc, Lead, and Smelting Company. However, limited, if any, milling operations occurred at the site. An April 2, 1967, visit to the Head Center and Grand Central Mines by an unknown entity showed that no mining activities were taking place there.

### **2.6.3 Far Mining Enterprises**

In March 1969, under ownership of Far Mining Enterprises, the Klondyke Mill was being overhauled to include a new crushing plant, which was being constructed west of the old mill building. Ore from the Iron Cap Mine was stockpiled during the reconstruction period. One source states that the mill's capacity was increased to 175 tons per day in 1969. In September 1969, Far Mining Enterprises was still conducting exploration work on its properties and had begun to open up an old Head Center Mine shaft. By late February 1970, Far Mining Enterprises had started up the Klondyke Mill and was preparing the Head Center Mine ready for production. However, by late June 1970, the operations of Far Mining Enterprises in the Aravaipa District had ceased due to financial difficulties. Undated notes collected from ADEQ files indicate that as of October 1970, Far Mining Enterprises had no success in refinancing and that all operations at the Klondyke Mill remained down.

### **2.6.4 Center Oil & Mining Company**

In December 1970, the Center Oil & Mining Company took over operations of the Aravaipa District mining claims and Klondyke Mill from Far Mining Enterprises. At that time, 11 people were employed at the mill. The ore processed at the mill came from the Head Center Mine, and plans were being made to start production from the Iron Cap Mine. However, by June 1971, the Klondyke Mill



had been shut down due to the Center Oil & Mining Company's lack of funds to keep the mill operational. Undated notes collected from ADEQ files state that a site visit in October 1973 indicated that most of the mill had been torn down.

### **2.6.5 Post-Mill Use**

In the 1970s, houses on the mill property were used as residential rental units. During the late 1970s through the 1990s, the Klondyke Mill property was used for cattle grazing. Environmental investigations began on the mill site in 1993.



## **3.0 SITE PHYSICAL CHARACTERISTICS**

### **3.1 TOPOGRAPHY**

The Aravaipa Creek drainage area can be subdivided from southeast to northwest into East Aravaipa Valley, Aravaipa Canyon, and West Aravaipa Valley. East Aravaipa Valley is wide and flat, narrowing from about 12 miles wide to 1.2 miles wide near the community of Klondyke. Aravaipa Canyon is approximately 18 miles long, up to 700 feet in height above the canyon floor, and varies from 100 to about 1,300 feet in width. West Aravaipa Valley widens out of Aravaipa Canyon into a large floodplain, which joins the San Pedro River.

The tailings are situated in the valley floor on the northern bank of Aravaipa Creek in East Aravaipa Valley (Figure 1). The valley floor at the Site has an elevation of approximately 3,650 feet above mean sea level, with the Galiuro Mountains rising to 7,500 feet to the southwest and the Santa Teresa Mountains rising to 6,166 feet to the northeast. The tailings are situated on a gently southwest-sloping alluvial fan deposited by Laurel Creek. The tailings are separated from the active channel of Aravaipa Creek by a 2- to 6-foot high cut bank, and from Laurel Creek by a man-made levee.

### **3.2 CLIMATE**

Aravaipa Creek is located in a semi-arid region characterized by two rainfall seasons. Winter seasons are characterized by low-intensity, long duration rainfall events from winter frontal systems. Winter high temperatures can range from 30 to 70 degrees Fahrenheit (°F), and snow is rare. Summer seasons are characterized by high-intensity, short duration rainfall from monsoonal thunderstorms, and temperatures commonly range from 60 to over 100 °F. As a result of intense storms, flash flooding naturally occurs in Aravaipa Valley, and these floods have continued to erode the stream banks near the location of the tailings (Fuller, 2002).

Klondyke averaged 14.1 inches of annual rainfall between 1952 and 1977, and 19.45 inches from 1978 through 1985. Between 1978 and 1989, the east and west ends of the canyon averaged 17.5 inches of annual rainfall. Precipitation may be up to 25 inches per year in the higher mountain areas (SCS, 1998).

### **3.3 GEOLOGY**

The Site is located along the northern boundary of the Basin and Range Physiographic Province. The Basin and Range Province is characterized by broad alluvium-filled basins separated by north-northwest trending block-faulted mountain ranges. However, because the Site vicinity is close to and



partially influenced by the Transition Zone Physiographic Province, it is characterized by a narrow valley having a thin layer of alluvial fill and hemmed in by mountains.

The Santa Teresa Mountains on the northeast side of East Aravaipa Valley include Precambrian granitic and metamorphic rocks, Precambrian sedimentary rocks, and Tertiary granitic rocks. The metamorphic and granitic rocks contain mineralized deposits that were mined and then processed at the Site. The Galiuro Mountains to the southwest include Tertiary volcanic and sedimentary rocks. The tablelands south and north of Aravaipa Canyon are cut by a number of tributaries, some of which form major canyons.

The lower slopes on both sides of East Aravaipa Valley consist of light brown Tertiary (Oligocene to Miocene) sedimentary rocks that have been incised and eroded by Aravaipa Creek. The valley floor consists of Quaternary unconsolidated fill material, from fine sands to cobbles, eroded from the surrounding mountains. Along the course of Aravaipa Creek, sediments are geologically young (Recent or Holocene) and unconsolidated.

The principal area of mining activity near the Site was on the western side of the Santa Teresa Mountains. The principal ore was located in the Grand Reef Lode System. The system extends about 11 miles from a point west of Buford Hill through Imperial Hill to Old Deer Creek (Ross, 1925). The narrow zone of mineralization occurs in intrusive rhyolite near the contact with the Santa Teresa Granite. The primary gangue minerals in the Grand Reef System are quartz and fluorite. Galena (lead sulfide) is the most abundant ore mineral, and has small amounts of argentite (silver sulfide) associated with it. Copper content generally increases with depth in the Grand Reef mine. Less abundant minerals include sphalerite, pyrite, chalcopyrite, and gold (Ross, 1925).

The closest mines to the investigation Site are the Tenstrike mine, Grand Reef mine, and the Dogwater mine. Tenstrike mine, the northernmost of the three, was reported to have produced 311 tons of lead ore in 1942 and a few tons of ore in 1952 (Ross, 1925). Grand Reef mine, located in Laurel Canyon, was mined from 1915 to 1941 and produced approximately 40,000 tons of ore that averaged approximately 8 to 9 percent lead, 1 to 2 percent copper, and 7 ounces of silver per ton. The only production reported in the Dogwater mine, located in the east branch of Laurel Canyon, was an unknown part of 117 tons of mixed ore from Grand Reef in 1920 (Ross, 1925). These mines and two mines farther to the north, the Iron Cap and Head Center mines, are reported to have provided most of the ore material that was processed at the Klondyke mill site (Simons, 1964).



## **3.4 TAILINGS CHARACTERISTICS**

### **3.4.1 Upper Tailings Pile**

The milling operations and the two tailings piles at the site are suspected as a primary source of metals contamination at the Site. Historically, the Upper Tailings Pile comprised approximately 4.0 acres, contained approximately 33,000 cubic yards of material, and ranged from 7 to 16 feet high. The southwest corner of the Upper Tailings Pile is located approximately 30 feet from the bank of Aravaipa Creek. Tailings material consists of very light brown to pinkish light orange, very fine-grained sand size particles resulting from the flotation mill processing of ore material. Long-term weathering of the tailings material has created a thin (1/4-inch thick) crust on the surface of the tailings that serves to reduce mobilization and migration of the tailings material by wind erosion. In some areas of the Upper Tailings Pile the surface exhibits a whitish-yellow stain indicative of deposition of metals salts due to evaporation of metals-saturated water. This staining is often an indication of acid rock drainage where the rainfall interacts with metals in the tailings to generate acidic solutions. There has been some storm water erosion of tailings on the western and southern edges of the Upper Tailings Pile into Aravaipa Creek. In addition, storm water runoff had carved several gullies into the tailings that carried runoff and tailings material off the tailings pile onto the surrounding soil and into Aravaipa Creek.

In May 2006, ADEQ directed URS to conduct a limited ERA at the Site. The ERA included constructing berms across the drainage gullies of both tailings piles to mitigate runoff during storm events. The berms were constructed in time to prevent runoff and additional erosion of the tailings piles during the large storm event that occurred in Aravaipa Valley in July 2006.

A large-scale construction ERA was conducted at the Site during April through June 2008. The Upper Tailings Pile was restructured and contoured, then capped with 2 feet of imported clean fill material, followed by installation of cobble-filled gabion mattresses around the full perimeter of the pile to protect it from a 50-year flood event. The capping soil was seeded to re-vegetate the pile and provide erosion protection.

### **3.4.2 Lower Tailings Pile**

The Lower Tailings Pile is approximately 200 feet downstream of the Upper Tailings Pile. This pile is 60 to 75 feet east of the bank of Aravaipa Creek, is approximately 36,000 cubic yards in volume, and up to 23 feet high. Although the surface of the Lower Tailings Pile is fairly compacted, there has been some erosion at the northwest corner of the pile into a narrow, shallow dry wash that flows southwest and parallel to the west edge of the tailings pile and drains to Aravaipa Creek. Much of the tailings material consists of very light brown to pinkish light orange very fine-grained sand size



particles resulting from the flotation mill processing of ore material. A portion of the southern end of the Lower Tailings Pile consists of gray to black, very fine-grained silty sand to silt. Long-term weathering of the tailings material has created a thin (1/4-inch thick) crust on the northern half of the surface of the tailings that serves to reduce mobilization and migration of the tailings material by wind erosion. The surface of much of the Lower Tailings Pile exhibits a whitish-yellow stain indicative of deposition of metals salts due to evaporation of metals-saturated water. This staining is often an indication of acid rock drainage where the rainfall interacts with metals in the tailings to generate acidic solutions. There has been some storm water erosion of tailings on the northern and southern edges of the Lower Tailings Pile into Aravaipa Creek. In addition, storm water runoff had carved several gullies into the tailings that carried runoff and tailings material off the tailings pile onto the surrounding soil and into Aravaipa Creek.

### **3.5 GRAND REEF MINE CHARACTERISTICS**

Tailings and waste rock in the vicinity of the Grand Reef Mine apparently have contributed metals contamination to the Site and vicinity. The sulfide minerals associated with the ore-bearing minerals commonly have impurities containing arsenic as replacement of lead, zinc and silver. Copper minerals also are present and increase with depth in the Grand Reef Mine.

The remnants of a tailings pile is located approximately 1/4 mile downstream from the mine on the north bank of Laurel Creek. The tailings pile is about 1 acre in size and consists of medium brown, finely laminated silt and clay material that apparently was historically built up behind a containment structure to a height of about 6 feet. The estimated volume of these tailings is 9,000 cubic yards. The eroded tailings pile is exposed as a cut bank along the north channel for about 150 feet. Within about 200 feet of the mine entrance more tailings/waste rock are deposited on both sides of the channel, and also have been eroded by Laurel Creek. These tailings/waste rock consist of light brown to reddish brown fine-grained sand and silt sized material, some of which may have been processed by stamping, which is less effective than the flotation process used at the Site. The estimated volume of the waste rock/tailings near the mine is 10,000 cubic yards. It appears that a large portion of the original tailings/waste rock materials have been eroded by the intermittent flow of Laurel Creek and transported downstream to be deposited on the Laurel Creek fan and in Aravaipa Creek. There is no visible indication of staining that would be indicative of acid rock drainage.

Three sampling events have been conducted to characterize soil and tailings from the Grand Reef Mine and Laurel Creek downstream of the mine. The sampling events include a University of Arizona thesis on the use of lead isotopes to characterize fate and transport of lead in 2003, sampling performed by URS at the request of ADEQ in 2008, and sampling performed by the U.S. EPA in 2012. Analytical results for those sampling events are discussed in Section 6.2 of this report.



## **3.6 SURFACE AND SUBSURFACE SOILS**

### **3.6.1 NRCS Soil Survey**

A General Soil Map and survey for Graham County, Arizona was released in 1973 by the Soil Conservation Service (U.S. Department of Agriculture, now Natural Resource Conservation Service [NRCS]). More recent or detailed soil surveys and mapping have been conducted for parts of Graham County, but not for the Site and vicinity. This soil map is intended for very general planning, and does not contain extensive details on each soil unit.

In the vicinity of the Site, the soils are part of the Grabe-Gila-Anthony Association. These soils are generally deep, well-drained, calcareous, and develop in alluvium on shallow slopes and floodplains. Soil is usually light brown, sandy loam. These soils have moderate infiltration rates, moderate to moderately rapid permeability, are slightly alkaline and have low shrink-swell potential.

### **3.6.2 Depth to Bedrock/Bedrock Geology**

The depth to bedrock is unknown, and was not encountered by deep borings used to install the four groundwater monitor wells. There is no information from ADWR files whether domestic or irrigation wells in the area have been drilled to bedrock.

A bedrock geologic map was prepared for the Site and vicinity by Fuller (2002). The map shows that bedrock consists of Tertiary-age Galiuro volcanic rocks. Those rocks outcrop in the low hills adjacent to the Site and are likely present at the Site beneath unconsolidated alluvium that is less than 200 to 300 feet thick.

## **3.7 SURFACE WATER HYDROLOGY AND STREAM SEDIMENTS**

### **3.7.1 Regional and Local Stream Conditions**

East Aravaipa Valley is drained by Aravaipa Creek and its tributaries. The Site is bounded by Aravaipa Creek to the southwest and Laurel Creek to the northwest. Laurel Creek is a tributary of Aravaipa Creek and their confluence is approximately 700 feet west (downstream) of the Lower Tailings Pile (Figure 2). Aravaipa Creek flows intermittently through much of its length to Aravaipa Canyon, approximately 2 miles downstream from the Site at the confluence with Stowe Gulch, where it becomes perennial. The primary source of water flow in Aravaipa Canyon is the groundwater aquifer in the upper portion of the watershed. At the head of the canyon, the stream flows on or close to bedrock, and groundwater underflow is forced to the surface. Stowe Gulch



Basin provides almost 48 percent of the annual discharge into Aravaipa Canyon (SCS, 1998). Aravaipa Creek flows as a perennial stream through the 18-mile-long Aravaipa Canyon. Once the creek leaves the canyon, the flow again becomes subterranean about five miles upstream from the confluence with the San Pedro River. In dry reaches, surface flow occurs only during times of heavy or persistent rainfall (SCS, 1998).

### ***3.7.1.1 Aravaipa Creek***

Aravaipa Creek near the Site has a drainage area of approximately 332 square miles. Aravaipa Creek is a meandering braided streambed with sand bars and gravel bars, 600 to 1,300 feet wide from bank to bank adjacent to the site. The nearest U.S. Geological Survey (USGS) gaging station (09473000) is more than 20 miles downstream near Mammoth, Arizona. The 2007 Floodplain Assessment conducted for the Site calculates the 100-year flood discharge at approximately 23,000 cubic feet per second (cfs) adjacent to the site. Additional discussion of Aravaipa Creek hydrology and hydraulics is provided in the 2002 and 2006 reports by JE Fuller Hydrology & Geomorphology, Inc. (Fuller 2002; 2006) and the 2007 Floodplain Mapping Study conducted by URS for this project (URS, 2007d).

### ***3.7.1.2 Laurel Creek***

Laurel Creek, located immediately north of the site, has a drainage area of approximately 7.37 square miles. The calculated 100-year flood discharge at Laurel Creek near the confluence with Aravaipa Creek is approximately 3,000 cfs. The Laurel Creek channel is typically straight, ranges from 40 to 100 feet wide, and narrows into Laurel Canyon approximately 1.5 miles north of the tailings site. Additional discussion of Laurel Creek hydrology and hydraulics is provided in the 2006 geomorphological report prepared by Fuller (2006) and the 2007 Floodplain Mapping Study conducted by URS (URS, 2007d).

## **3.8 GROUNDWATER HYDROGEOLOGY**

The Aravaipa Valley groundwater basin is bounded on the south by a drainage divide located approximately 21 miles southeast of Klondyke that separates the Aravaipa Creek drainage to the northwest from the Sulphur Springs Valley and Willcox Basin drainage to the southeast. Extensive drawdown of groundwater to irrigate the Willcox Basin has not affected groundwater levels in Aravaipa Valley (Hadley, 1991). An estimated 2.4 percent of annual rainfall reaches groundwater through recharge within the basin (SCS, 1998). Groundwater recharge to the aquifer may occur from springs and subsurface flows near the basin margins, infiltration of runoff into streambeds, and direct infiltration of precipitation from the ground surface (ADWR, 2002a).



Water wells located in the vicinity of the Site are typically completed in the shallow alluvium. Well depths vary from 10 to 100 feet and may yield up to 1,200 gpm (SCS, 1998). However, some wells in the vicinity of the Site produce less than 10 gpm. The subsurface alluvial sediments in Aravaipa Valley vary with depth and lateral distance from the valley slopes. Wells near the center of the valley and in the Aravaipa Creek floodplain generally are completed in coarse grained sand and gravel and produce larger amounts of water. Wells installed at upslope locations are completed in finer grained or thinner alluvial units and include more clay layers, which results in lower well productivity.

The majority of groundwater is used for irrigation, with minor amounts used for stock watering and domestic purposes (ADWR, 2002b; 2002c). Hadley reported that historical groundwater use was greater in the 1950s, when water was used to process ore at the Klondyke Mill and to support a large population employed in milling operations (Hadley, 1991).

Groundwater elevation varies by season and rainfall/drought conditions. Groundwater depletion may result from evapotranspiration, pumping, and down gradient stream discharge. Depth to groundwater typically ranges from 20 to 45 feet below ground surface (bgs), and the depth to groundwater under the streambed may be 4 to 6 feet during a very wet season.

### **3.8.1 Groundwater Elevation**

Groundwater elevation varies by season and rainfall/drought conditions. Groundwater depletion may result from evapotranspiration, pumping and down gradient stream discharge. Depth to groundwater ranged from 37 to 43 feet bgs in the recently installed groundwater monitoring wells. During a site reconnaissance in May 2002, URS measured the depth to water at approximately 40 feet in Well No. 3, which is located in the streambed 350 feet southwest of the Upper Tailings Pile.

Groundwater elevation data were collected on a quarterly basis from November 2005 through October 2007 to assess changes in groundwater elevation and assist in identifying the causes of any elevation changes, such as seasonal variations or offsite activities that may impact groundwater levels. Groundwater elevation data collection was resumed on an annual basis in April 2012. During the period from November 2005 through October 2007, groundwater elevations rose by an average of 7 feet. Most of the rise in groundwater elevation occurred following flooding along Aravaipa Creek in July and August 2006. When comparing groundwater elevations from October 2007 to the April 2012 data, groundwater elevations decreased by an average of 7 feet.

### **3.8.2 Groundwater Flow Direction and Gradient**

The groundwater hydraulic gradient is calculated quarterly from a map on which groundwater elevation data are posted. When plotted on a map, the groundwater hydraulic gradient and flow



direction are used to assess changes to the groundwater flow regime from previous sampling events. The groundwater flow direction at the site from November 2005 through February 2013 was generally parallel to Aravaipa Creek, primarily to the north by northwest. The hydraulic gradient at the site has varied from approximately 0.0015 ft/ft to 0.005 ft/ft over the monitoring period.

### **3.8.3 Onsite Monitoring Wells**

The four monitoring wells located at the Site were sampled during nine quarterly events from November 2005 to October 2007, and resumed on an annual basis in April 2012 and February 2013. Analytical results for those sampling events for general chemistry parameters that describe the characteristics of groundwater beneath the Site are discussed here. Analytical results for the sampling events for 14 total and dissolved metals are discussed in Section 5.7.8.1 of this report.

### **3.8.4 Offsite Domestic Wells**

Four domestic water wells located outside the Site boundaries were sampled to assess water quality offsite and to assist in characterizing groundwater quality in the area. Analytical results for metals in domestic well samples are discussed in Section 6.7.8.2 of this report. The domestic wells generally had slightly lower alkalinity, cation and sulfate concentrations, and slightly higher chloride and fluoride concentrations. None of the parameters was detected at concentrations indicative of contamination or poor water quality.

In July 2001, ADEQ conducted a regional groundwater sampling event of domestic wells up-gradient and down-gradient of the Site. Wells in the vicinity of the Site that were sampled include domestic wells on parcels 110-47-001i, 110-47-006, and 110-47-003d. Domestic wells up-gradient of the Site include Garwood and Sollers-1. Wells down-gradient of the Site include three wells on Cobra Ranch (CR-01 through CR-03), Sollers-2, Stampfer, Luepke, Franzone, and Nature Conservancy wells (NC-OK, NC-GH, and NC-MH). The regional domestic wells are illustrated on Figure 3.



## 4.0 PREVIOUS INVESTIGATIONS

### 4.1 HISTORICAL ASSESSMENTS OF WATER QUALITY

In 1977 the Department of Botany and Microbiology at Arizona State University (ASU) conducted a microchemical analysis of Aravaipa Creek and adjacent aquatic habitats relative to land and water use management. Fifteen water quality sampling stations were established along the Aravaipa Creek and its tributaries from downstream of the tailings piles to the confluence of the San Pedro River. Sampling was conducted in August 1976, October 1976, November 1976 and January 1977. The samples were analyzed for dissolved and total metals.

Except for one mercury sample, the study concluded that metals were within water quality standards in effect at the time. However, the total metals concentrations of lead exceeded current drinking and agricultural water use standards which are applicable to Aravaipa Creek. The maximum concentration of lead was found to be 146 micrograms per liter ( $\mu\text{g/L}$ ), which is higher than the current ADEQ Surface Water Quality Standard (ASWQS) for full body contact of 15  $\mu\text{g/L}$ .

Also, reported concentrations of copper, lead, selenium, and zinc in the perennial reach of Aravaipa Creek (SCS, 1998) and lead in the vicinity of Klondyke tailings (ADEQ, 1993), were greater than the hardness-adjusted National Ambient Water Quality Criteria (NAWQC) (EPA, 1996). In the long term, this may increase risk to fish, invertebrates, or insectivorous and piscivorous birds or mammals.

Furthermore, metals concentrations in surface water can rise dramatically during storm events when bottom sediments are re-suspended and surface runoff leaches water-soluble metals and salts into the creek. Since many fish and amphibian species hatch during the spring when rain events are common, they may be exposed to higher than normal concentrations of dissolved metals and lower than normal pH. Although fish and amphibian eggs are relatively tolerant to metal and low pH exposure, egg-sac fry, alevins, and tadpoles are much more sensitive than adults. Therefore, water quality conditions that are non-threatening to adults could cause adverse effects on juvenile life history stages. In this regard, continuous water sampling during the spring, especially during storm events, could provide useful information to evaluate ecological risk.

The Klondyke tailings have been designated as a WQARF site because preliminary investigations identified conditions at the Site that potentially may adversely impact human health and the environment. This section summarizes the results of previous investigations of tailings, surface and subsurface soil, surface water and stream sediment, and groundwater conducted during the initial assessment of the Site.



## **4.2 BUREAU OF LAND MANAGEMENT, 1987**

The BLM and ADEQ monitored water quality by collecting water samples from six locations in the perennial reach of Aravaipa Creek between 1986 and 1992 (summarized by SCS, 1998). Samples were analyzed for general chemistry and metals. The results, summarized by SCS (1998), indicated that, except for iron, the detected concentrations of metals did not exceed recommended water quality standards.

## **4.3 ADEQ, 1993 PRELIMINARY ASSESSMENT/SITE INSPECTION**

In 1993 the USFWS reported to ADEQ that erosion of the tailings piles may be contaminating Aravaipa Creek. Subsequently ADEQ conducted sampling, which was done by Peter Hyde "The Klondyke Tailings and Aravaipa Creek Water Quality, March and April 1993". A total of 10 soil samples were collected from the two tailings piles and analyzed for metals. Arsenic and lead were detected at concentrations exceeding the corresponding Arizona Residential Soil Remediation Levels (R-SRLs) of 10 milligrams per Kilogram (mg/kg) and 400 mg/kg, respectively. Antimony, cadmium, and lead were detected at concentrations exceeding the corresponding Arizona minimum Groundwater Protection Levels (GPLs) of 35 mg/kg, 29 mg/kg, and 290 mg/kg, respectively (ADEQ, 1993).

Three sediment samples were collected from Aravaipa Creek channel southwest of the tailings piles and analyzed for total metals. Lead was detected in one sample at a concentration exceeding the GPL of 290 mg/kg (ADEQ, 1993).

During spring flood conditions in March and April 1993, two samples of the shallow groundwater (less than six feet bgs), or more correctly the subflow in Aravaipa Creek, were collected immediately down gradient of the Site from the channel of Aravaipa Creek and analyzed for total metals by EPA method 200 series (ADEQ, 1993). Analytical results indicated that the subflow adjacent to the Site contained arsenic, cadmium, copper, lead and zinc at concentrations exceeding the corresponding ASWQS for full body contact. ADEQ recommended engineering controls to mitigate erosion of the tailings (ADEQ, 1993).

Three surface water samples were collected from Aravaipa Creek in the vicinity of the tailings piles during the flow stage in 1993. In addition, two surface water samples were collected from the perennial reach of Aravaipa Creek northwest of the Site. The five surface water samples were analyzed for general chemistry and total metals. No metals were detected at concentrations exceeding the laboratory reporting limits (ADEQ, 1993).



#### **4.4 PUBLIC HEALTH ASSESSMENT, 1997**

The Agency of Toxic Substances and Disease Registry (ATSDR), in cooperation with the Arizona Department of Health Services (ADHS), conducted a public health assessment of the Klondyke Mine Tailings at the request of ADEQ and EPA in 1997 (ADHS, 1999). The objective of the health assessment was to evaluate the health risk associated with exposure from the abandoned Klondyke mine tailings. The ATSDR was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and used as a fund to identify and clean up hazardous waste sites. The EPA and states regulate the investigation and cleanup of the sites.

The Site first gained attention after the USFWS reported elevated levels of lead and arsenic in protected fish species during routine monitoring. It was believed that the eroding tailings piles from the Klondyke mill site were contaminating the creek water, which is a habitat for seven species of native fish on the endangered or threatened lists. The USFWS lodged a complaint with ADEQ in 1993.

Contaminants of concern were selected from previous studies based on the contaminant concentrations as compared to background levels, health based comparison values, and community concerns. The contaminants of concern were further evaluated by ADEQ and ATSDR based on toxicological evaluation and health outcome data in order to determine their public health implications. Contaminants of concern are lead and arsenic in the tailings, soil and stream bed sediment; boron, iron, and manganese in surface water; and arsenic, cadmium, mercury, and lead in fish samples. Human exposure to each contaminant was an estimation of exposure concentrations and pathway-specific doses. Exposure scenarios were determined according to site and vicinity usage by residents and visitors including camping and use of all-terrain vehicles (ATVs) on impacted soils and in dry river beds, recreational swimming and bathing in the perennial portion of Aravaipa Creek downstream from the Site, and ingestion of fish caught in the creek.

A pathway analysis was performed to determine how human receptors may be exposed to the contaminants. The analysis consisted of identifying the contaminant source, mode of transport, point and potential route of exposure, and the existence of the receptor population. The following pathways of exposure were identified: inhalation of dust, soil ingestion, dermal exposure, fish consumption, and ingestion from fruits or vegetables grown in contaminated soils. Residents that are most likely to be exposed were identified based on the frequency and length of exposure.

The results of the health assessment suggest that the Site does not pose a health risk to nearby residents, campers, swimmers or ATV users. The ingestion of fish caught in Aravaipa Creek does



not appear to present an adverse health risk. A new evaluation would be recommended if land use or chemical concentrations change to assess potential exposures (ADHS, 1999).

#### **4.5 ADEQ, 1997/SCS, 1998 PRELIMINARY ASSESSMENT/SITE INSPECTION**

In 1997, ADEQ conducted additional chemical evaluations of the tailings and surrounding soil (ADEQ, 1997). Eleven soil samples were collected from the two tailings piles and surrounding soil and analyzed for metals. SCS Engineers (SCS) reported in the *Klondyke Tailings Response Strategy Analysis* that arsenic and lead were detected at concentrations exceeding the corresponding R-SRLs of 10 mg/kg and 400 mg/kg, respectively (SCS, 1998). Arsenic, cadmium, and lead were detected at concentrations exceeding the corresponding GPLs of 58 mg/kg, 29 mg/kg, and 290 mg/kg, respectively (SCS, 1998).

SCS conducted an assessment of sediments in Aravaipa and Laurel creeks in 1997. In Aravaipa Creek, the concentrations of metals in sediments were elevated adjacent to the tailings, but below the SRLs. Sediments upstream and downstream of the tailings contained low levels of metals. Samples were collected to a depth of 4 to 6 inches. A sediment sample collected at a depth of 4 to 6 inches in Laurel Creek upstream of the Site contained lead at concentrations above the GPL of 290 mg/kg; In addition, the TCLP concentration of lead in the sample exceeded the regulatory limit of 5.0 milligrams per liter (mg/L) (SCS, 1998).

Groundwater samples were collected from the floodplain of Aravaipa Creek, down gradient of the tailings piles. The samples were analyzed for total metals. No metals were detected at concentrations exceeding the corresponding AWQS, where established (SCS, 1998).

#### **4.6 SCS, GRAF (1997)**

In support of the *Klondyke Tailings Response Strategy Analysis* prepared by SCS Engineers (SCS, 1998), a fluvial morphology field investigation was completed by Dr. William Graf (1997). That investigation included the collection and analysis of three tailings samples. Although not analyzed by an Arizona-licensed laboratory, the results for total metals were consistent with previous investigative results.

All three soil samples collected by Graf exceeded the Arizona Non-Residential Soil Remediation Level (NR-SRL) and R-SRL for arsenic. The three soil samples also exceeded the R-SRLs for beryllium and manganese. Elevated levels of lead were detected in all three samples (SCS, 1998).



#### **4.6.1 King and Martinez (1997) Metals in Fish**

Whole body fish were taken from Aravaipa Creek on October 28, 1997, by Kirke King and Mike Martinez and analyzed for arsenic, cadmium, lead, and mercury. Analytical results for arsenic, cadmium, and lead indicated that fish from Aravaipa Creek were highly contaminated, but the effect of this contamination is difficult to quantify. However, seven species of native fish thrived in the creek, which suggested that 1997 levels of contaminants were below adverse effect thresholds. King and Martinez recommended that proactive efforts should be made to prevent further contamination of the creek (SCS, 1998).

#### **4.7 EPA, 2010**

In 2010, the EPA began a soil removal assessment for the residential properties near the Klondyke Tailings WQARF Site. The soil removal assessment was based on elevated lead and arsenic concentrations determined through the site characterization. The EPA collected soil samples from approximately 200 square-foot areas around the primary residential living area of five parcels (Ecology and Environment, Inc., 2010). The EPA also collected additional bioavailability samples in 2011 to aid in the removal assessment (Ecology and Environment, Inc., 2012).

#### **4.8 EPA, 2012/2013**

From May through June 2012 and October through November 2013, The EPA Superfund Technical Assessment and Response Team (START) conducted soil removal activities at three residential parcels and within the source area parcels within the Site. Soil removal activities occurred on parcels 110-47-001m (EPA label HS-04), 110-47-003d (EPA label HS-05), and 110-47-006 (EPA label HS-03). The Ecology and Environment, Inc. report, dated February 2014, documenting the soil removal activities is included as Appendix A. Parcels selected for soil removal activities are shown on Figure 2 of Appendix A.

Soil with elevated lead and arsenic concentrations was excavated to a depth of 1-foot bgs in residential yards and to a depth of 2 feet bgs in designated garden areas, for a total of approximately 1,500 cubic yards of removed material. The EPA conducted additional characterization and limited soil removal activities on the hillside on parcel 110-47-006 where tailings from past smelting activities were located.

The EPA set the site-specific lead action level of 800 mg/kg at properties that did not report that children visited and 400 mg/kg at properties where the homeowners reported that children visit (Ecology and Environment, Inc., 2014). An arsenic action level of 34 mg/kg was established by the EPA; however lead concentrations determined the removal action areas. The EPA performed



confirmation soil sampling and documented lead and arsenic concentrations left in place at the residential parcels. The excavations were subsequently backfilled to original grade with borrow material from Aravaipa Creek mixed with imported soil amendment, with select areas seeded. Limits of excavation are included in the Ecology and Environment, Inc. report, dated February 2014, attached as Appendix A.

The EPA conducted soil excavation removal activities in two areas within the source area parcel, labeled Area A and Area D, as shown in Figure 2 of Appendix A. Approximately 5,000 cubic yards of soil with elevated concentrations of lead and arsenic and tailing material were excavated from these areas.

The Lower Tailings Pile was graded and reshaped to accept excavated material from the three residential parcels and from areas within the source area parcels. All excavated material from the soil removal activities was consolidated on the Lower Tailings Pile and left as temporary cap material. The EPA did not implement permanent capping and stabilization of the Lower Tailings Pile.



## **5.0 EARLY RESPONSE ACTION**

URS conducted electromagnetic, magnetometer, and metal detector geophysical surveys at the Site in 2002. The results of the geophysical survey are documented in the Geophysical Survey Report and are summarized in Section 4.1 (URS, 2004). As a result of the geophysical surveys, 10 targets that could not be explained by surface metallic objects or other visible Site features were noted.

In May 2006, URS performed a field investigation as part of the early response action. Field activities included the excavation and removal of identified geophysical targets (Section 4.2), characterizing and removal of laboratory reagents (Section 4.3), and repair of major erosion features on the tailings piles (Section 4.4). The field activities are documented in the Final Early Response Action Completion Report (URS, 2006).

In 2008, URS completed construction activities at the Upper Tailings Pile. The Upper Tailings Pile was consolidated and stabilized to prevent migration of contaminants downstream via surface water from flooding events (Section 4.5).

### **5.1 GEOPHYSICAL SURVEY**

#### **5.1.1 Rationale and Setup**

The objective of the geophysical survey was to use a noninvasive approach to delineate potential locations of buried drums, wells, tanks, pipelines, equipment and other significant artifacts or antiquities located at the Site. The Klondyke community had reported that drums of cyanide may have been buried at the Site in the past.

The geophysical survey included both a magnetometer survey and a separate electromagnetic conductivity survey to assess the presence of buried ferrous metals. The use of two independent and complimentary surveys was intended to help reduce or eliminate ambiguities in data interpretation and to provide a more refined identification of potential targets. Once the combined magnetic and conductivity data sets were completed, results from each survey could be graphically overlain and trends identified. Anomalies identified via this method would then be more precisely located using a high lateral resolution metal detector.

The geophysical survey encompassed approximately 34 acres of the original 80-acre area, due to the presence of large stands of dense, mature vegetation indicating a lack of historical development or usage, and former residences that were not likely to have received buried drums or tanks. A rectangular grid was staked out using lines running parallel to the long axis of the survey area (parallel to magnetic north-south) (URS, 2004c). Survey pin flags and whiskers were placed 100 feet



apart in the east-west and north-south directions along each survey line. The precise location of each staked survey point was recorded using a Trimble ProXRS™ high-resolution GPS instrument.

The magnetometer and electromagnetic conductivity instruments are susceptible to background interference in locations of disturbed soils and exposed ferrous materials, both of which were found at the site. In some locations, such as the more developed processing area, metal equipment and debris caused erratic responses in the instrumentation. Detailed field notes recorded surface metal equipment and other features that potentially may affect the instrument responses. During layout/survey of the grid lines potential surface interference materials, such as power lines, metal equipment, piping, tanks, drums, debris areas, vehicle parts and foundations were surveyed and noted. A field sketch of the site was developed showing potential surface interference materials (URS, 2004c).

## **5.1.2 Survey Methodology**

### **5.1.2.1 Magnetometer**

The magnetic survey was performed using a Geometrics G-858 MagMapper™ cesium magnetometer, which measures the intensity of the Earth's magnetic field. Variations in this field may be caused by the natural distribution of iron oxides within the soil and rock of a site or by the presence of buried steel or iron objects. The magnetometer does not respond to nonferrous metals.

The instrument was operated in discrete mode, with data points collected at intervals of every 25 feet along each survey grid line. The operator conducted the survey by pacing along each survey line at a distance of 25 feet between each survey measurement point, or station. At each station, the survey measurement point identification was verified by the operator, who then pressed the "record" button to enter the magnetometer reading in the MagMapper™ datalogger. The operator took precautions to make sure that the instrument boom was orientated parallel to the survey line in a roughly north-south direction before taking a reading at a measurement point. Twice daily the data recorded and stored in the datalogger were downloaded to a field laptop computer. Data were collected in separate daily files, corrected for diurnal variations, and then consolidated into a master data file at the completion of the magnetometer survey. These data were then exported as x, y, z coordinate data files, where x and y represent the survey point physical location and z the measured total field intensity, then contoured using the Surfer® contouring program.

Contour intervals for the magnetometer map were plotted at 1,000 nanoteslas (nT), 500 nT, and 250 nT (URS, 2004c). A contour interval of 1,000 nT is considered an acceptable interval for a reconnaissance survey over a site having a large areal extent, while a contour interval of 250 nT is more suitable for detailed surveying to locate small buried targets, such as drums. The ambient



magnetic field for the Site varied between 48,500 nT and 49,500 nT, and measured values ranged from 29,450 nT to 52,218 nT. The average magnetic field measurement was 48,802 nT and the median value was 48,850 nT.

### **5.1.2.2 Electromagnetic Conductivity**

Subsurface conductivity of the Site was measured using a Geonics<sup>®</sup> EM31-MK2 Terrain Conductivity Meter with digital data recorder. Terrain conductivity is a function of the type of soil and rock, soil porosity and permeability, and the chemistry of the fluids that fill the pore spaces. The instrument yields a signal proportional to the conductivity of the earth between the transmitter and receiving coil to an effective depth of approximately 8 to 10 feet.

The electromagnetic conductivity survey was conducted after the magnetometer survey, and was performed in the horizontal co-planar mode, measuring both the quadrature and inphase components. The inphase component is primarily used for detection of metal objects, although metal objects also affect the quadrature phase measurement. The survey grid was traversed in a north-south direction with the instrument pole oriented north-south. At each survey station, the operator observed the instrument readings with the instrument pole oriented north-south, then rotated the instrument pole 90 degrees to an east-west orientation and observed the readings.

Data recorded and stored in the datalogger were downloaded twice daily to a field laptop computer. Data were collected in separate daily files, and then consolidated into a master data file at completion of the conductivity survey.

All data collected and stored on the geophysical instruments were downloaded on the day of data acquisition. At the completion of the conductivity survey, data from different days were consolidated to create one master file. These data were then exported as x, y, z coordinate data files, where x and y represent the survey point physical location and z the measured terrain conductivity. These data were then contoured using the Surfer<sup>®</sup> contouring program. Contour intervals for the quadrature-phase conductivity maps were plotted at 40 millisiemens per meter (mS/m), 20 mS/m and 10 mS/m using the Surfer<sup>®</sup> program (URS, 2004c). A contour interval of 40 mS/m is a generally accepted interval for a reconnaissance survey over a site having a large areal extent, while a contour interval of 10 mS/m is suitable for detailed conductivity survey to locate small buried targets, such as drums.

Contour intervals for the inphase conductivity maps were plotted at 4 parts per thousand (‰), 2 ‰, and 1 ‰ of primary electromagnetic field using the Surfer<sup>®</sup> program (URS, 2004c). Ambient quadrature-phase conductivity values for the site varied from 30 mS/m to 40 mS/m. Due to the presence of scattered metal surface debris, measured values for the site ranged from -162 mS/m to +205 mS/m. The average quadrature-phase conductivity value was 38.3 mS/m and the median value



31.4 mS/m. Ambient inphase conductivity values ranged from -6 to +6 ‰. Measured values ranged from -20 to +20 ‰, with an average value of -3.27 ‰ and a median of -3.56 ‰.

### **5.1.2.3 Metal Detector**

Target locations for the metal detector survey were selected from the results of the magnetometer and electromagnetic conductivity surveys performed at the Site. Geophysical anomalies identified during those surveys are listed in the Final Geophysical Survey Report (URS, 2004c). The anomalies were classified by whether the locations had strong, moderate, or weak indicators of a buried source of magnetic and electromagnetic disturbances. In general, a metal detector survey was conducted at each of the strong and moderate sources of magnetic and electromagnetic disturbances.

A Geonics EM61-MK2 Data Logging System was used to conduct the high-resolution metal detector survey. It is a high-sensitivity 4-channel time-domain metal detector that can detect a single 55-gallon drum at a depth of over 10 feet beneath the instrument, yet is relatively insensitive to interference from nearby metallic features such as fences, buildings, cars, etc. It was operated in AUTO mode over a small-scale survey grid having one-foot spacing to survey areas A through M (URS, 2004c).

The metal detector also was operated in scanning mode in areas having dense vegetation or surface features that precluded the setting up of a grid system and/or systematic surveying of the location using the 6-foot-long pole of the metal detector (URS, 2004c). In the SCANNING mode, the head of the metal detector was moved in a lateral sweeping motion as the area of interest was traversed from a known starting point to a known finishing point.

### **5.1.3 Magnetometer and Conductivity Results**

In general, magnetic anomalies are concentrated in the processing area and around the upper and Lower Tailings Piles. No significant magnetic anomalies are observed in the channel of Aravaipa Creek.

The combined use of the magnetometer survey data and inphase component of the electromagnetic conductivity data identified several potential subsurface metal targets. Once locations of overlapping magnetometer and conductivity anomalies were identified, field notes were reviewed to identify any obvious source of interference present at each location. Using the geophysical and field notes information, a subset list of locations having strong, moderate, or weak indicators of a buried source of magnetic or electromagnetic disturbance was compiled. Those locations were further investigated using the high-resolution metal detector.



#### **5.1.4 Metal Detector Results**

Geophysical disturbance anomaly locations were verified by the metal detector survey and were found to be concentrated in the processing area and around the Upper and Lower Tailings Piles. No locations were identified in the channel of Aravaipa Creek. The Final Geophysical Survey Report (URS, 2007a) recommended further investigation at ten locations.

As part of the 2006 ERA, additional investigation of the anomalies was conducted by excavation of those 10 locations. URS subcontracted Environmental Response, Inc. (ERI), an Arizona-licensed environmental remediation and hazardous waste disposal contractor, to conduct the exploratory excavation work. None of the targets was large enough to be considered a possible buried tank. Three targets identified were possibly indicative of a drum-size metallic object. The metal detector had limited success locating and tracing the extent of small-diameter buried metallic pipe that we anticipate was historically used to supply water to the buildings in the processing area.

The excavations encountered several buried or partially buried, rusted and crushed empty metal drums, buried inactive pipeline fragments, and miscellaneous metal debris that likely was responsible for an anomaly. There was no visible indication of stained or impacted soil at the drum or pipeline locations.

### **5.2 GEOPHYSICAL EXCAVATION**

The ten geophysical targets identified during previous field activities were excavated to determine the nature of each target in May 2006. Metallic debris found through excavation included metal crushing balls, copper grounding cable, deteriorated sections of steel pipe, a covered steel septic tank, a small metallic disc, a steel pipe leading to a rock-lined septic tank, a partially buried drum, and random metallic debris.

### **5.3 LABORATORY REAGENT REMOVAL**

Previous Site investigations observed containers of labeled and unlabeled reagents and process chemicals used for historical Site activities including reagents for assaying of ore material, process chemicals for milling, and other materials for equipment and vehicle maintenance.

In May 2006, URS and ERI went through the buildings designated as the laboratory and the repair shop to characterize and remove containers of labeled and unlabeled reagents and process chemicals. At the direction of ADEQ and with the permission of the landowner, additional chemicals were characterized and removed from the Site at that time. ADEQ has also received information, during previous Site interviews, of anecdotal reports that one or more drums of cyanide have been buried at



the Site. However, after excavating the geophysical targets identified through the geophysical survey, no drums containing cyanide were found.

#### **5.4 TAILINGS PILES EROSION REPAIR**

In May 2006 URS directed ERI to repair major erosion features on the tailings piles. This was accomplished by using the loader bucket of the backhoe to move tailings and form berms above major drainages that have formed. Three berms were constructed on the Upper Tailings Pile and two berms were constructed on the Lower Tailings Pile.

#### **5.5 UPPER TAILINGS PILE CONSOLIDATION**

In the spring and early summer of 2008 as part of the early response action by ADEQ, construction activities were performed to contain and stabilize the Upper Tailings Pile and prevent migration of contaminants downstream via surface water from flooding events or into the groundwater via infiltration of stormwater. These construction activities included:

- Acquisition of a County Road Maintenance Permit and Stormwater Construction General Permits.
- Removal of approximately 2,000 cubic yards (cu yds) of tailings eroded from the Lower Tailings Pile, closest to Aravaipa Creek, for placement and compaction on the Upper Tailings Pile. This was followed by the grading, shaping and compaction of the tailings on the Upper Tailings Pile (insert November 2008 Upper Tailings Pile completion report reference).
- Placement and compaction of a 2-foot thick soil cap on the top and sides of the Upper Tailings Pile using approximately 17,000 cu yds of imported clean soil to protect against physical contact with the contaminated tailings and to reduce infiltration that could impact groundwater quality. The design also includes a minimum three (3) percent grade on the Upper Tailings Pile capping system to promote stormwater runoff to the perimeter and thus further reduce the opportunity for infiltration. The imported soil used for the soil cap and part of the backfill at the toe of slope came from a borrow site located on Bureau of Land Management (BLM) property.
- After the earthwork and gabion construction was completed the top of the soil cap on the Upper Tailings Pile were scarified and reseeded with hydromulch. It is anticipated that some native vegetation will eventually also become established.
- Installation of approximately 10,500 square yards (sq yds) of rock-filled gabion mattresses all around the perimeter of the Upper Tailings Pile slope for protection from erosion during a



100 year flooding event. Also, the gabion mattresses were installed on the pile embankment slope to a depth below grade designed to protect against scour and undercutting during a 100-year flood event. The rock for the gabions was imported from a source near Duncan, Arizona.

- Construction of the Upper Tailings Pile capping system commenced in March 2008 and was completed by the end of June 2008.



## **6.0 STUDY AREA INVESTIGATION**

At the beginning of the Klondyke project, it was generally expected that metals contamination was derived from the tailings piles and was likely contained within the original WQARF site boundary that was composed of source area parcels 110-47-003g and 110-47-003h. However, the results of soil sampling revealed that metals contamination extended outside the source area parcels up to as much as 1,800 feet to the west, north and east. Those results indicated the potential for a larger area of contamination from historic milling activities, windblown or surface water movement of metals contamination as well as other sources of metal contamination may exist in the vicinity of the Site.

URS was retained by the ADEQ to conduct site characterization studies at the Klondyke Tailings WQARF Site as part of the Site RI. The purpose of this task was to evaluate the nature and extent of heavy metal contamination in soil and sediment at and in the vicinity of the Site. The area to be studied as part of this project includes the Upper and Lower Tailings Piles and processing area, adjacent properties, a portion of the 100-year floodplain and channel of Aravaipa Creek, and a portion of Laurel Creek adjacent to the Site.

The objective of the remedial investigation task was to determine the nature and extent of contamination in tailings, soils, sediments, surface water, and groundwater at the Site.

### **6.1 TAILING CHARACTERIZATION**

#### **6.1.1 2002 Acid Base Accounting Samples**

URS collected samples from the Upper and Lower Tailings Piles for Acid Base Accounting (ABA) studies during two mobilizations in 2002. ABA involves the determination of the different sulfur species which are used in determining the acid generation potential (AGP) and acid neutralization potential (ANP) of a sample. The ANP is compared to the AGP of the sample to establish net neutralization of the sample. The samples are classified as potentially acid-generating, potentially non-acid-generating and unknown acid-generating potential depending on the ratios of ANP to AGP and the net neutralization potential. Based on the recommendations of ADEQ for the ABA Static Tests Part I, 40 samples were collected from each of the two tailings piles during the first mobilization: 20 surface samples and 20 subsurface samples. Please refer to the Final Geochemistry Static Tests Report for selected sampling locations from each tailings pile (URS, 2003a). The large number of samples from each tailings pile was required to obtain statistically significant information on the geochemistry characteristics of the two tailings piles. Surface (0 to 6 inches) and subsurface (1 foot to 3 feet) samples were collected at each sampling location to evaluate any vertical variation in the geochemistry. Details of the sampling procedures are presented in the Final Static Tests Report (URS, 2003b).



Based on the results of the Static Tests Part I, eight sampling locations were selected for Static Tests Part II and kinetic tests, and samples were collected during the second mobilization. The eight sampling locations were selected based on results of the Part I testing that identified their acid-generating potential: two were potentially non-acid-generating, two had uncertain acid-generating potential, and four were potentially acid-generating.

Analysis of those samples for metals reported the following metals at concentrations greater than ten times their average crustal abundance: arsenic, cadmium, copper, manganese, lead and zinc. These metals may have a higher tendency to leach from the tailings (URS, 2006a).

Arsenic and lead were detected at concentrations exceeding the corresponding NR-SRL. Arsenic was detected at concentrations ranging from 32 to 159 mg/kg, which exceeds the NR-SRL of 10 mg/kg. Lead was detected at concentrations ranging from 1,940 to greater than 10,000 mg/kg, which exceeds the NR-SRL of 800 mg/kg.

### **6.1.2 Static Tests (Acid Base Accounting)**

The ADEQ requested an evaluation of the geochemical stability of the tailings prior to conducting a remedial investigation/feasibility study (RI/FS) at the Site. Results of geochemistry tests of the tailings are used to assess long-term environmental impacts at and in the vicinity of the Site. A geochemistry study combines the evaluation of acid rock drainage (ARD) and metal leaching potential of the tailings. Mobilization of several metals is typically enhanced under acidic conditions. The results will be used to characterize:

- Spatial variability of ARD (areal extent and vertical profiles)
- Rates of acid generation, neutralization and metal leaching
- Estimation of time to exhaustion of acid generation
- Drainage chemistry.

This information will be used to evaluate potential downstream environmental impacts and develop environmental management and mitigation measures.

The standard international practice for determining the likelihood of ARD involves several types of static and kinetic tests that are conducted and compared (Morin and Hutt, 1998). These tests result in redundancies and crosschecks that are critical for accurate prediction of ARD and metal leaching. At Klondyke, a three-stage approach involving Static Tests Part I, Static Tests Part II, and Kinetic Tests was implemented.



Static Tests Part I includes analysis of paste conductivity, paste redox, paste pH and ABA.

Static Tests Part II includes elemental analysis by Inductively Coupled Plasma (ICP) emission spectrometry scan and mineralogy analysis by electron microprobe scanning.

### **6.1.3 Results of Static Tests**

**Static Tests I** - Results of the Static Tests Part I for 80 Klondyke tailings samples included paste conductivity, paste redox, and paste pH, which were used to calculate ABA for the tailings piles. The Klondyke samples were classified as being potentially non acid-generating, potentially acid-generating, or having uncertain acid-generating potential. The results are presented in the Statics Test Report (URS, 2003a). The results confirmed that samples from both tailings piles are predominantly potentially acid-generating.

**Static Test II** - The results of geochemistry Static Tests Part II for eight Klondyke tailings samples included elemental analysis by ICP scan and mineralogy by electron microprobe analysis. ICP scan provides a whole rock analysis of the main elements that comprise a sample. ICP results are presented in the Statics Test Report (URS, 2003a). A total of 30 elements considered to be of environmental interest at the Site were analyzed.

High concentrations of calcium were observed in the samples, ranging from 1.0 to 3.6 percent. Based on mineralogical analysis and ABA, the calcium exists predominantly in the form of calcite and gypsum. Samples with low ANP contain calcium in the form of gypsum. Samples with high ANP contain calcium as calcite. The following metals exist at concentrations greater than the tenfold crustal abundance: arsenic, cadmium, copper, manganese, lead and zinc. Although the results do not confirm that these metals are leaching, it does indicate that they may potentially leach from the tailings.

Arsenic was detected at concentrations ranging from 32 to 159 mg/kg, which exceeds the NR-SRL of 10 mg/kg. Lead was detected at concentrations ranging from 1,940 to greater than 10,000 mg/kg, which exceeds the NR-SRL of 800 mg/kg.

Mineralogical analyses were conducted on eight samples as part of Static Tests II. While the ICP scan identifies the elements in a sample, mineralogy identifies the contributing minerals. The complete mineralogical results identify the main acid-generating minerals, acid-neutralizing minerals, and acid neutralization products identified in the tailings (URS, 2003a).

Of the 40 samples collected from the Upper Tailings Pile, 32 are acid-generating and the remaining eight are potentially non acid-generating (URS, 2003a). As discussed in the Statics Test Report, the



two distinct types of materials are located in two different portions of the Upper Tailings Pile. The results suggest that the two distinct types of materials might be from different geological units.

Of the 40 samples collected from the Lower Tailings Pile, 28 are potentially acid-generating, eight have uncertain acid-generating potential, and four are potentially non acid-generating (URS, 2003a). In contrast to the Upper Tailings Pile, there is no correlation between the spatial distribution of samples on the Lower Tailings Pile and their acid generation potential classification, nor are the samples generally distinguishable by color or texture.

#### **6.1.4 Kinetic Tests (Acid Base Accounting)**

Kinetic Tests are used to evaluate the rates of acid generation and metal leaching and leachate quality. Although static tests provide a way of determining the acid generation potential and the metal content of the material, they cannot be used to estimate the rate of acid generation or metal leaching, or leachate quality. Kinetic tests are bench-scale laboratory tests run for a period of up to 6 months with repeated analyses to obtain leaching rates and leachate quality (URS, 2003).

#### **6.1.5 Results of Kinetics Tests**

The following observations were based on the results and discussion presented in the Kinetics Test Report (URS, 2003b). Samples labeled KUT were collected from the Upper Tailings Pile and samples labeled KLT were collected from the Lower Tailings Pile. Samples KUT- 4&5, KUT-16 and KLT-2, which the Static Tests results classified as potentially acid generating, had the following characteristics that confirmed the acid generating potential:

- Acidic pH (2.78 to 6.12).
- High acid production rates, ranging from 60 to over 1,000 milligrams/kilogram/week (mg/kg/wk).
- Very low or non-existent alkalinity production rates ranging from 0 to 4 mg/kg/wk.
- High metal leaching rates and mobility, in most cases exceeding ADEQ AWQS and EPA Maximum Contaminant Levels (MCL).
- Redox potentials generally above 400 millivolts, which indicates a fairly strong oxidizing potential.
- Sulfate concentrations were high throughout the duration of the tests. However, not all the sulfate products resulted from oxidation of contained sulfide; most of the sulfate was



produced from the dissolution of sulfate minerals or from previous sulfide mineral oxidation products.

Samples KUT-1 and KLT-3, which were classified as potentially non-acid generating in the Static Tests results, had the following characteristics that confirmed non-acid generating potential:

- pH close to neutral - ranging from 6.39 to 7.56
- Very little or non-existent acid production rate ranging from 0 to 7 mg/kg/wk.
- Alkalinity production rates ranging from 3 to 19 mg/kg/wk.
- Lower metal leaching rates and mobility, although some metals concentrations exceeded the AWQS.
- Sulfate concentration was generally high, but the mobilized sulfate was not acidic: it resulted from dissolution of contained sulfate minerals and not from oxidation of contained sulfide minerals.

Samples classified as having uncertain acid generating potential, KLT-7&8, KLT-12 and KLT-16 exhibited the following characteristics during the kinetic testing period:

- pH close to neutral, ranging from 6.67 to 7.80.
- Very little or non-existent acid production rate ranging from 0 to 14 mg/kg/wk.
- Alkalinity production rates ranging from 2 to 39 mg/kg/wk.
- Low metal leaching rates, although some metals concentrations exceeded the AWQS.

### **6.1.6 Lead and Arsenic Bioavailability**

ADEQ requested the collection of bioavailability samples prior to conducting the RI activities at the Site. The bioavailability results were used in preliminary evaluation of potential risk and to determine the scope of RI characterization. Typically, site-specific bioavailability data are helpful when selecting inputs for risk models. It is generally good practice to select sampling locations for lead and arsenic bioavailability based on known distributions of total lead and arsenic at the Site. Because this sampling was conducted prior to the RI, the sampling locations were selected based on previous sampling conducted by ADEQ in 1993 and 1997.



### **6.1.6.1 Drexler Bioavailability Study**

#### **6.1.6.1.1 Soil Sample Collection**

Dames & Moore (2000) collected and tested six soil and tailings samples for the presence of metals, lead speciation, and lead and arsenic bioavailability. Sampling locations were selected based on the highest reported lead concentrations at the Site. One shallow sample (0 to 6 inches bgs) and one deep sample (approximately 3 feet bgs) were collected from each tailings pile. Additionally, two shallow soil samples were collected from the former production area between the tailings piles.

Surface soil samples were collected from the Site using a decontaminated stainless steel spoon and mixing bowl. The upper 1 inch of the tailings was weathered to form a crust and a portion of that crust was removed.

Subsurface samples were collected by first advancing a decontaminated stainless steel hand auger to a depth of 3 feet to create a borehole. Samples were collected using a stainless steel split spoon sampler lined with a brass sleeve attached to a drive hammer assembly. Once two brass sleeves were filled with the subsurface sample using the drive hammer, they were transferred to a decontaminated stainless steel mixing bowl and homogenized using a decontaminated stainless steel spoon. The sample was then divided between two brass sleeves, packaged, labeled, and preserved in a cooler.

#### **6.1.6.1.2 Soil Sample Analysis**

The six samples collected were submitted to Dr. John Drexler, University of Colorado at Boulder, and analyzed for lead speciation, and lead and arsenic bioavailability using an in-vitro analysis method. The in-vitro procedure is designed to simulate sample digestion in animals and is referenced as bulk lead/arsenic. The results are used to calculate bioavailable lead and arsenic from the total lead and arsenic concentrations in the sample. Six samples were also submitted to NEL Laboratories in Phoenix, Arizona for total lead and arsenic analysis.

### **6.1.6.2 Cannon Microprobe Study**

URS collected eight soil samples and placed them in quart-sized plastic bags and shipped the samples to Cannon Microprobe of Seattle, Washington to characterize the mineralogy of the soils with emphasis on metal bearing, acid generating, acid neutralizing, and metal adsorption mineralogy of soils at the Klondyke Tailings WQARF. Cannon Microprobe used x-ray diffraction and scanning electron microscopy with electron microprobe analysis to characterize the mineralogy of the soils (Cannon, 2000).



### 6.1.7 Results of Bioavailability Tests

Analytical results are provided in Table 2. The table includes the equivalent ADEQ historical sample number, location, and sample color, where applicable.

**Lead** - Total lead (as analyzed by NEL Laboratories by standard methods) was detected in the four tailings samples at concentrations ranging from 4,000 mg/kg to 22,000 mg/kg. Total lead was detected at concentrations of 5,600 mg/kg and 31,000 mg/kg in two soil samples collected at the former production area. Bulk lead (as analyzed by the University of Colorado by in-vitro analysis method) was detected in the four tailings samples at concentrations ranging from 2,845 mg/kg to 27,183 mg/kg. Bulk lead was detected at concentrations ranging from 8,575 mg/kg to 34,541 mg/kg in two soil samples collected at the former production area.

Bioavailable lead was detected in the four tailings samples at values ranging from 0 to 99 percent. Bioavailable lead was detected at values ranging from 52 to 86 percent in the two soil samples collected at the former production area.

**Arsenic** - Total arsenic (as analyzed by NEL Laboratories by standard methods) was detected in the four tailings samples at concentrations ranging from 91 mg/kg to 120 mg/kg. Total arsenic was detected at concentrations ranging from 64 mg/kg to 110 mg/kg in two soil samples collected at the former production area. Bulk arsenic (as analyzed by the University of Colorado by in-vitro analysis method) was detected in the four tailings samples at concentrations ranging from 70 mg/kg to 109 mg/kg. Bulk arsenic was detected at concentrations ranging from 73 mg/kg to 92 mg/kg in two soil samples collected at the former production area.

Bioavailable arsenic was detected in the four tailings samples at values ranging from 2 to 6 percent. Bioavailable arsenic was detected at values ranging from 4 to 19 percent in the two soil samples collected at the former production area.

Analytical results revealed a large range of lead concentration in tailings and soil samples collected at the Site. Based on the limited number of samples collected there is no correlation between the amount of weathering and the lead concentration in the tailings piles. However, the data show that the bioavailability of lead in surface tailings samples is essentially zero, compared with a bioavailability of 0 to 99 percent in subsurface tailings samples. Based on the limited number of samples collected there is no correlation between the amount of weathering and the arsenic concentration in the tailings piles. Additionally, there is no apparent correlation between arsenic bioavailability and tailings sample depth.



## **6.2 MINE ORE / WASTE ROCK CHARACTERIZATION**

### **6.2.1 Aravaipa Group Mines and Prospects**

To identify the possible sources of lead pollution in the perennial reaches of Aravaipa Creek, a study was conducted using lead isotopes, strontium isotopes, and total metals (Morfin, 2003). Isotopes were analyzed at the University of Arizona (UofA) Isotope Laboratory. The investigation included the collection and analysis of samples from the mine waste, tailings, ore, and streambed sediments from five mine locations: the Sinn Finn Mine, the Iron Cap Mine, the Head Center Mine, the Grand Reef Mine, and the Klondyke tailings site. The results suggest the tailings deposited by the flotation mill at the Klondyke Tailings WQARF site are derived from the Iron Cap, Sinn Fein and Head Center mines near Aravaipa and may be a major source of lead. Analysis of lead isotopes in the sediments of Aravaipa Creek suggest that the tailings have migrated and have reached the Aravaipa Canyon Wilderness Area.

### **6.2.2 Grand Reef Group Mines and Prospects**

#### **6.2.2.1 Historical Sampling (University of Arizona Thesis)**

The Morfin (2003) Investigation included the collection and analysis of samples from the mine waste, tailings, ore, and streambed sediments from five mine locations: the Sinn Finn Mine, the Iron Cap Mine, the Head Center Mine, the Grand Reef Mine, and the Klondyke tailings site. The data excluded the Grand Reef Mine area as a significant contributor to the high levels of metals in the stream bed of Laurel Creek. Morfin (2003) concluded that there are two sources of lead in the Aravaipa District: the natural lead ore of the Santa Teresa Mountains, and a mixed lead oxide/lead sulfide ore. The investigation concluded that lead contamination in both the ephemeral and perennial reaches of the Lower Aravaipa Creek is likely derived from mill tailings at the Klondyke tailings piles.

Morfin (2003) reports the metals in the Klondyke area are more available for transport during monsoon flooding events even though Grand Reef mine waste sediments in Laurel Creek are discernible on the canyon floor. The metals concentrations in the Klondyke Tailings are lower than the metals concentrations at the Grand Reef site because the processing at the Grand Reef mine was less effective than the flotation process used at Klondyke. However, due to the Grand Reef mining process, the lead rich particles are highly susceptible to aqueous transport during large storm events and any surface water flow from Laurel Creek.



### **6.2.2.2 URS Sampling at Grand Reef Mine**

In June 2008 URS traversed up Laurel Creek and visited the Grand Reef Mine. Approximately 1/3 mile downstream from the mine and within sight of the Grand Reef geologic structure, URS observed small clumps of brown, finely laminated silt and clay within the light gray sand and gravel sediments of the Laurel Creek streambed. Approximately 1/4 mile downstream from the mine, URS observed the remnants of a tailings pile on the north bank of the channel. The tailings pile was approximately one acre in size and consisted of brown, finely laminated silt and clay material that apparently was built up behind an earthen dam or berm to a height of about 6 feet. The containment structure had been breached at some time in the past by seasonal flows down Laurel Creek, and a portion of the tailings was eroded away and carried down Laurel Creek. The eroded tailings pile was exposed along the north bank of the channel for about 150 feet. Within about 200 feet of the mine entrance more tailings/waste rock deposits were observed on both sides of the channel that also had been eroded by Laurel Creek.

URS collected tailings/waste rock material at the mine and on the banks of Laurel Creek immediately down gradient from the mine (Figure 4). In addition, URS collected samples of possible tailings material in the dry Laurel Creek channel ¼-mile down gradient from the mine. Those samples were collected using clean disposable plastic trowels and placed in 8-ounce glass jars. The samples were submitted to Environmental Science Corporation (ESC) and analyzed for 13 priority pollutant metals. ESC is an Arizona-licensed analytical laboratory (ADHS License No. AZ0612). The results of these analyses are reported in Section 6.3.

### **6.2.2.3 EPA Sampling of Grand Reef Mine**

In November, 2011, the Superfund Technical Assessment and Response Team (START) collected 21 surface soil samples from the Laurel Creek, Grand Reef Mine, and two tributaries downstream of the Dog Water/Silver Cable Mine, reference Sampling Results Map from the Grand Reef Report prepared by Ecology and Environment, Inc. for the EPA, Appendix B. The samples were sent to an EPA lab and analyzed for total metals. Ten samples contained concentrations of lead exceeding the investigative action level of 400 mg/kg. The soil samples contaminated with lead were generally found in mine waste areas along banks of Laurel Creek near the Grand Reef Mine. The START recommended further evaluation of surface and subsurface soils in Laurel Creek to determine if lead contamination derived from the Grand Reef Mine is a source for lead in surface soils of residences near Laurel Creek. (Ecology and Environment Inc., 2012)



### **6.2.3 Results of the Grand Reef Mine Sampling**

In June 2008, URS collected five samples from the Grand Reef Mine area:

- Two samples from the wall of a partially eroded mill tailings pile located approximately 1/5 mile down gradient (south) from the mine and sited on the north bank of Laurel Creek [GR-2 and GR-5]
- One sample of residual tailings material that was eroded from the tailings pile, transported downstream, and deposited in the Laurel Creek sediment approximately 1/4 mile south of the mine [GR-1]
- One sample of waste rock or mine debris located at the base of the entrance to the mine north of Laurel Creek [GR-4]
- One sample of Laurel Creek sediment located approximately 100 feet upstream from the mine entrance [GR-3].

The five samples were analyzed for 13 priority pollutant metals by EPA Methods 6010B and 7471. The results are provided in Table 3. The results indicate that lead and arsenic are present in the four tailings and waste rock samples at the Grand Reef Mine at concentrations ranging from 13,000 to 170,000 mg/kg and 530 to 890 mg/kg, respectively, which significantly exceed the corresponding NR-SRLs. These materials currently are being eroded during storm events and transported downstream in Laurel Creek. The sediment sample collected upstream from the mine entrance [GR-3] contained lead at concentrations of 600 mg/kg, which exceeds the R-SRL. Arsenic was not detected in that sample.

## **6.3 SURFACE AND SUBSURFACE SOIL CHARACTERIZATION**

### **6.3.1 Sampling Rationale**

Soil sampling for site characterization at and in the vicinity of the Site was conducted in two rounds. The initial soil sampling was implemented in March 2006 and completed in May 2006. Following a large storm event in July 2006, additional soil sampling was conducted in October and November 2006 and again in May and October 2007. The site characterization is documented in the Final Site Characterization Report (URS, 2013).

Soil sampling was conducted beginning within the source area parcels to characterize the lateral and vertical extent of soil contamination by lead, arsenic and other metals. An onsite mobile laboratory equipped with Energy-Dispersive X-ray Fluorescence (EDXRF) equipment was selected to analyze soil samples for metals. Results of the daily sampling events would be used to determine “step-out”



locations with the intent of delineating the lateral and vertical extent of lead concentrations exceeding soil remediation levels.

### **6.3.2 Initial Sampling Event**

URS established a surface soil sampling grid within the source area parcels that covers the Site with a grid line spacing of 50 feet (Figure 5). The sampling grid was placed and recorded from previously surveyed base station points using the onsite navigation capabilities of a portable Global Positioning System (GPS) instrument capable of sub-meter accuracy. A total of 648 grid line intersects were recorded in accordance with the ADEQ Locational Data Policy and in State Plane coordinates (feet). The grid line intersects were used as surface soil sampling points.

URS sampled surface soils at 0 to 3 inches bgs to characterize surface soil conditions at the Site. Collected samples were originally assigned sequential numbers beginning in the southeast corner (0N; 0W) on grid line intersects moving to each grid line intersect north to the original Site boundary and then continuing at each new row to the west. After initial results were obtained and plotted, the grid was expanded in three directions to attempt to fully characterize the lateral extent of contamination at the Site. A total of 1,779 grid line intersects, including the initial 648 points, were established. A new sample identifier scheme was also implemented to reflect the north and east or west position (in feet) relative to the starting point (0N; 0W) for all collected samples.

During this event, surface soil samples were collected at 673 of 1,779 grid line intersects resulting in a total of 673 original and 65 duplicate surface soil samples for analysis. Areas in the immediate vicinity of the 30 historical surface soil and tailings samples previously collected by the ADEQ in 1993, 1997 and 2000 were not investigated. Additionally, where planned sampling locations were obstructed with existing structures or concrete slabs, the sample was collected from exposed surface soil as close to the planned sampling location as possible.

### **6.3.3 Additional Sampling**

The results of the initial sampling concluded in June 2006 indicated that field investigation activities would need to be continued in order to further characterize the lateral and vertical extent of metals contamination in soils at the Site. The previously established sampling grid was ultimately expanded to 3850 feet (east-west) by 3250 feet (north-south) resulting in a total of 5,005 grid line intersects. Additional surface and shallow subsurface soil samples (up to 24" bgs) were collected to characterize the site. Overall, soil samples were collected at a total of 1,122 grid line intersects resulting in a total of 450 original and 40 duplicate surface samples and 998 original and 105 duplicate shallow subsurface soil samples for analysis.



### **6.3.4 Subsurface Soil Sampling**

Subsurface soil samples were collected from boreholes during drilling of four groundwater monitor wells and from five soil borings located in the production area and where tailings have eroded off of the tailings pile (Figure 6). Boring logs are provided in Appendix C. Subsurface soil samples were collected from the borings at depths of 1, 5, and 10 feet.

### **6.3.5 Surface Soil Sample Collection Techniques**

URS sampled soils from 0 to 3 inches bgs to characterize surface soil conditions at the Site. Surface soil samples were collected from a total of 1,122 grid line intersects using a decontaminated stainless steel trowel or spoon. Each sample was placed in a clean 4-ounce glass jar, labeled with the sampling location, date and time of collection, and submitted to the onsite mobile laboratory for analysis of total metals using a field-portable EDXRF instrument. After two days of sampling it became evident that the mobile laboratory could not process soil samples as quickly as they were being collected. To reduce field costs, the mobile lab was released and the samples were analyzed using the same equipment at the fixed-base laboratory in Phoenix. Sediment samples collected after the flood event in 2006 were also submitted to the fixed-base laboratory for analysis of total metals using the same EDXRF instrument. Although the samples were analyzed by a fixed-base laboratory, they are referenced by the type of analysis performed, e.g. EDXRF.

Review of analytical results indicated that lead was the most prevalent contaminant in the soil. Consequently, the sampling results for lead were plotted on a gridded site map to identify areas where lead concentrations in soil exceeded the R-SRL. The lateral extent of surface soil contamination was then further defined by collecting surface soil samples at a 50-foot grid spacing between select 100-foot samples to resolve where the concentration of lead exceeded the corresponding R-SRL.

### **6.3.6 Subsurface Soil Sample Collection Techniques**

A total of nine borings were advanced using a rotosonic drill rig operated by Prosonic. The rotosonic drilling method was used to advance soil borings because it provided a continuous core of the soil, which avoided cross contamination of deeper soil samples and allowed visual examination of a vertical soil profile for subsurface sample collection.

Four of the nine borings were advanced for the installation of groundwater monitor wells. The remaining five borings were selected to provide additional areal assessment of the Site for characterization. Soil samples were taken from the continuous core collected from the nine borings at 1, 5, and 10 feet intervals bgs. These borings were backfilled after sample collection. No difficult



conditions precluded advancement of the borings to 10 feet bgs. Subsurface soil samples were placed in a clean 4-ounce glass jar, labeled with the sampling location, date and time of collection, and placed in a re-sealable plastic bag in a cooler with ice to be submitted to a fixed-base laboratory for analysis of total metals. A total of 30 subsurface soil samples were collected, including 3 duplicate samples for analysis.

In addition, at select 475 gridline intersects around the Site shallow subsurface samples were collected at 6 inches, 12 inches and 24 inches bgs. These samples were collected using a decontaminated stainless steel hand auger. The samples were placed in a clean 4-ounce glass jar, labeled with the sampling location, date and time of collection, and submitted to the analytical laboratory for analysis of total metals. A total of 1,103 shallow subsurface soil samples were collected, including 107 duplicate samples for analysis.

### **6.3.7 Analytical Methods**

#### **6.3.7.1 Sample Analyses**

Soil samples were screened for metals by EDXRF using the same instrument either in a mobile field laboratory or at the fixed-base laboratory. Analytes reported by EDXRF analysis included 10 total metals: antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc. Approximately 10 percent of the samples sent to the fixed-base laboratory were analyzed for those metals by EPA Method 6010B/7471A. Select samples were also analyzed for cyanide by EPA Method 9010B/9014, pH by EPA Method 9040/9045, and some or all of the following metals by EPA Method 6010B: aluminum, barium, beryllium, boron, calcium, cobalt, iron, magnesium, molybdenum, potassium, selenium, silver, sodium, thallium, and vanadium.

Sample packaging, preservation, and analytical methods were conducted as stipulated in the Quality Assurance Project Plan (QAPP). Samples were submitted to Transwest Geochem, Inc. (Transwest) in Phoenix, Arizona for analysis. Transwest (purchased by Xenco in 2010) is an Arizona-licensed (No. AZ0133) analytical laboratory with Arizona Department of Health Services (ADHS). Analytical methods were performed in general accordance with EPA document *SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (EPA, 1994). Samples were delivered to the analytical laboratory using the chain of custody (COC) procedures discussed in Section 4.4.4.

#### **6.3.7.2 Screening Using EDXRF**

Samples that were analyzed using EDXRF at the laboratory were first dried in an oven at a temperature not exceeding 40 degrees centigrade. Samples were then screened through a 10-mesh



sieve. Approximately 10 grams of each sample was removed and pulverized using a ball mill to a rock flour consistency (between 100 and 200 mesh).

After sample preparation, a field portable Spectrace QuanX EDXRF Spectrometer was used to screen samples for total metals. The instrument was calibrated prior to sample screening using standards provided by the laboratory. The calibration of the instrument was verified at regular intervals. The screening EDXRF results for those samples were compared to the fixed laboratory results as part of an on-going quality control evaluation.

### **6.3.7.3 Fixed-Base Laboratory Analysis**

A total of 330 (approximately 10 percent) EDXRF-screened samples collected from the Site, were submitted to a fixed-base laboratory for total metals analysis to confirm field screening results. Some of these selected samples were also analyzed for pH and cyanide. In addition, all 30 subsurface boring samples were also submitted to a fixed-base laboratory for total metals, pH, and cyanide analysis. Samples were analyzed by the EPA-approved methods listed in Section 4.4.1.

## **6.3.8 Results of Soil Sampling**

A total of 2,406 soil samples from the Site were submitted for EDXRF analysis of metals. In addition, a total of 330 EDXRF samples and 30 soil boring samples were submitted to the fixed-base laboratory for total metals analysis by EPA Methods 6010B/7471A. Some of these samples were also analyzed for pH and cyanide by EPA Methods 9040/9045 and 9010B/9014, respectively. Soil sample laboratory analytical reports prepared by Transwest are provided in Appendix C.

### **6.3.8.1 EDXRF Analysis of Soil Samples**

Field screening results for samples from the Site are presented in Tables 4, 5, 6, and 7. Field screening results for metals were evaluated by comparing observed concentrations with R-SRLs and minimum GPLs, where applicable. Exceedances of both the R-SRLs and minimum GPLs were indicated for antimony, cadmium, lead, and mercury for soil sampling locations at and in the vicinity of the Site. In addition, exceedances of the R-SRLs were indicated for copper, manganese, and zinc at the same soil sampling locations. Lead was the only metal detected above the minimum GPL and R-SRL in the sediment samples. In addition, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

Arsenic was also detected in many soil and sediment samples at concentrations that exceeded the R-SRL. Arsenic is commonly associated with lead in the Klondyke tailings. However, there were issues with the ability of the EDXRF meter to properly detect arsenic when lead was present in the soil sample. The EDXRF results indicated raised detection limits or elevated concentrations for



arsenic whenever lead concentrations were shown in the sampled locations. The elevated detection limits were typically an order of magnitude less than the corresponding detected lead concentration. Further investigation on the cause of this occurrence indicates that the EDXRF Spectrometer utilized at the time of the investigation had limitations in analyzing for arsenic in the presence of lead. Lead x-rays (from EDXRF) produce two strong spectral peaks at energies 10.5 and 12.6 keV. The most intense arsenic spectral peak is also at 10.5 keV and is therefore strongly affected by the presence of lead in the sample. Thus, the presence of lead in a sample elevates the arsenic detection level. Based on these findings, a majority of the EDXRF arsenic results are considered invalid and unusable, with the exception of when arsenic was shown to be <10 mg/kg. The EDXRF Results are described in detail in the final site characterization report (URS, 2013a). Panel maps of Figures 5 and 7 through 9 are included as Appendix I.

#### 6.3.8.1.1 Surface Soils

At a sampling depth of 0 to 3 inches for surface soil sampling, a total of 1,122 primary samples and 106 duplicate samples were analyzed (Table 4). Exceedances of both the R-SRLs and minimum GPLs were indicated for antimony, cadmium, mercury, and lead at soil sampling locations at and in the vicinity of the Site. In addition, exceedances of the R-SRLs were indicated for copper, manganese, and zinc at the same soil sampling locations. As previous stated and further discussed below, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

**Antimony** concentrations were recorded at a maximum of 120 mg/kg and were greater than or equal to the R-SRL of 31 mg/kg in 78 of the 1,228 samples analyzed. In addition, 54 of these 78 samples have antimony concentrations greater than or equal to the minimum GPL of 35 mg/kg. **Note:** In all but one case where antimony exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Cadmium** concentrations were recorded at a maximum of 1,400 mg/kg and exceeded the minimum GPL of 29 mg/kg and the R-SRL of 39 mg/kg in 72 of the 1,228 samples analyzed. An additional 22 samples have cadmium concentrations greater than or equal to the minimum GPL of 29 mg/kg. **Note:** In all cases where cadmium exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Mercury** concentrations were recorded at a maximum of 230 mg/kg and exceeded the minimum GPL of 12 mg/kg and the R-SRL of 23 mg/kg in 75 of the 1,228 samples analyzed. An additional 45 samples have mercury concentrations greater than or equal to the minimum GPL of 12 mg/kg. **Note:** In all but six cases where mercury exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.



**Copper** concentrations ranged from 11 mg/kg to 15,000 mg/kg and exceeded the R-SRL of 3,100 mg/kg in 22 of the 1,228 samples analyzed. There is no minimum GPL established for copper. **Note:** In all cases where copper exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Manganese** concentrations ranged from 64 mg/kg to 68,000 mg/kg and exceeded the R-SRL of 3,300 mg/kg in 124 of the 1,228 samples analyzed. There is no minimum GPL established for manganese. **Note:** In all cases where manganese exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Zinc** concentrations ranged from 34 mg/kg to 98,000 mg/kg and exceeded the R-SRL of 23,000 mg/kg in 41 of the 1,228 samples analyzed. There is no minimum GPL established for zinc. **Note:** In all cases where zinc exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Lead** concentrations ranged from 13 to 50,000 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 794 of the 1,228 samples collected. An additional 102 samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg. In addition, since lead is the most frequently detected contaminant that exceeded action levels, its EDXRF results are posted on a map of the study area (Figure 5).

**Arsenic** data were determined to be usable for 99 results, where the concentrations were less than the instrument's detection limit of 10 mg/kg (See Section 5.1.1.4). It is likely that many of the samples analyzed with high lead content also had high arsenic concentrations, although they are not reported because of the limitations of the EDXRF. It should be noted that arsenic concentrations in native soils in Arizona often exceed the SRL. A state-wide study conducted for ADEQ, showed that background concentrations of arsenic in native soil range from 0.2 to 97 mg/kg (Earth Technology, 1990).

#### 6.3.8.1.2 Soils at 6 Inches

At a sampling depth of 6 inches, a total of 528 samples (476 primary and 52 duplicates) were collected and analyzed (Table 5). Exceedances of both the R-SRLs and minimum GPLs were indicated for antimony, cadmium, mercury, and lead at soil sampling locations at and in the vicinity of the Site. Exceedances of the R-SRLs were also indicated for copper, manganese, and zinc at the same soil sampling locations. In addition, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.



**Antimony** concentrations were recorded at a maximum of 86 mg/kg and were greater than or equal to the R-SRL of 31 mg/kg in 21 of the 528 samples analyzed. In addition, 15 of these 18 samples have antimony concentrations greater than or equal to the minimum GPL of 35 mg/kg. **Note:** In all cases where antimony exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL.

**Cadmium** concentrations were recorded at a maximum of 1,800 mg/kg and exceeded the minimum GPL of 29 mg/kg and the R-SRL of 39 mg/kg in four of the 528 samples analyzed. An additional three samples have cadmium concentrations greater than or equal to the minimum GPL of 29 mg/kg. **Note:** In all but two cases where cadmium exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Mercury** concentrations were recorded at a maximum of 120 mg/kg and exceeded the minimum GPL of 12 mg/kg and the R-SRL of 23 mg/kg in seven of the 528 samples analyzed. An additional 17 samples have mercury concentrations greater than or equal to the minimum GPL of 12 mg/kg. **Note:** In all but six cases where mercury exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Copper** concentrations ranged from 13 mg/kg to 32,000 mg/kg and exceeded the R-SRL of 3,100 mg/kg in 2 of the 528 samples analyzed. There is no minimum GPL established for copper. **Note:** In one case where copper exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Manganese** concentrations ranged from 17 mg/kg to 5,700 mg/kg and exceeded the R-SRL of 3,300 mg/kg in 3 of the 528 samples analyzed. There is no minimum GPL established for manganese. Further discussion on the lateral distribution of this compound is provided in Section 6.3. **Note:** In all cases where manganese exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Zinc** concentrations ranged from 17 mg/kg to 77,000 mg/kg and exceeded the R-SRL of 23,000 mg/kg in four of the 528 samples analyzed. There is no minimum GPL established for zinc. **Note:** In all cases where zinc exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Lead** concentrations ranged from 23 to 26,000 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 180 of the 528 samples collected. An additional 54 samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg. In addition, since lead is the most frequently detected contaminant that exceeded action levels, its EDXRF results are



posted on a map of the study area (Figure 7). Further discussion on the lateral distribution of this compound is provided in Section 6.3.

**Arsenic** data were determined to be usable for 112 results, where the concentrations were less than the instrument's detection limit of 10 mg/kg.

#### 6.3.8.1.3 Soils at 12 Inches

At a sampling depth of 12 inches, a total of 464 samples (418 primary and 46 duplicates) were collected and analyzed (Table 6). Exceedances of both the R-SRLs and minimum GPLs were indicated for antimony, cadmium, mercury, and lead at soil sampling locations at and in the vicinity of the Site. Exceedances of the R-SRLs were also indicated for manganese and zinc at the same soil sampling locations. In addition, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

**Antimony** concentrations were recorded at a maximum of 86 mg/kg and were greater than or equal to the R-SRL of 31 mg/kg in nine of the 464 samples analyzed. In addition, five of these nine samples have antimony concentrations greater than or equal to the minimum GPL of 35 mg/kg. **Note:** In all cases where antimony exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL.

**Cadmium** concentrations were recorded at a maximum of 160 mg/kg and exceeded the minimum GPL of 29 mg/kg and the R-SRL of 39 mg/kg in two of the 464 samples analyzed. An additional one sample has cadmium concentrations greater than or equal to the minimum GPL of 29 mg/kg. **Note:** In all but one case where cadmium exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL.

**Mercury** concentrations were recorded at a maximum of 240 mg/kg and exceeded the minimum GPL of 12 mg/kg and the R-SRL of 23 mg/kg in eight of the 464 samples analyzed. An additional seven samples have mercury concentrations greater than or equal to the minimum GPL of 12 mg/kg. **Note:** In all but five cases where mercury exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Manganese** concentrations ranged from 27 mg/kg to 4,600 mg/kg and exceeded the R-SRL of 3,300 mg/kg in one of the 464 samples analyzed. There is no minimum GPL established for manganese. **Note:** In the case where manganese exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Zinc** concentrations ranged from 11 mg/kg to 60,000 mg/kg and exceeded the R-SRL of 23,000 mg/kg in two of the 464 samples analyzed. There is no minimum GPL established for zinc.



**Note:** In all cases where zinc exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Lead** concentrations ranged from 20 to 18,000 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 83 of the 464 samples collected. An additional 32 samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg. In addition, since lead is the most frequently detected contaminant that exceeded action levels, its EDXRF results are posted on a map of the study area (Figure 8).

**Arsenic** data were determined to be usable for 152 results, where the concentrations were less than the instrument's detection limit of 10 mg/kg.

#### 6.3.8.1.4 Soils at 24 Inches

At a sampling depth of 24 inches, a total of 111 samples (104 primary and seven duplicates) were collected and analyzed (Table 7). Exceedances of both the R-SRLs and minimum GPLs were indicated for antimony, mercury, and lead at soil sampling locations at and in the vicinity of the Site. In addition, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

**Antimony** concentrations were recorded at a maximum of 90 mg/kg and were greater than or equal to the R-SRL of 31 mg/kg in seven of the 111 samples analyzed. In addition, three of these seven samples have antimony concentrations greater than or equal to the minimum GPL of 35 mg/kg. **Note:** In all cases where antimony exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL.

**Mercury** concentrations were recorded at a maximum of 24 mg/kg and exceeded the minimum GPL of 12 mg/kg and the R-SRL of 23 mg/kg in one of the 111 samples analyzed. An additional five samples have mercury concentrations greater than or equal to the minimum GPL of 12 mg/kg. **Note:** In all cases where mercury exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Lead** concentrations ranged from 17 to 7,200 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 18 of the 111 samples collected. An additional one sample has lead concentration greater than or equal to the minimum GPL of 290 mg/kg. In addition, since lead is the most frequently detected contaminant that exceeded action levels, its EDXRF results are posted on a map of the study area (Figure 12).

**Arsenic** data were determined to be usable for 53 results, where the concentrations were less than the instrument's detection limit of 10 mg/kg.



### **6.3.8.2 Fixed-Base Laboratory Analysis of Soil Samples**

A total of 330 (approximately 10 percent) EDXRF-screened soil samples collected from the Site, were submitted to a fixed-base laboratory for total metals analysis to confirm field screening results, verify the lead concentrations reported by EDXRF are statistically accurate, and establish a relationship between metals concentrations and potential sources of contamination (Table 8).

The 104 soil samples collected during the initial round of sampling were retained for laboratory analyses for the following:

- 95 soil samples were analyzed for arsenic, cadmium, lead, antimony, copper, manganese, and zinc utilizing Test Method 6010B;
- 27 soil samples were analyzed for aluminum, barium, boron, calcium, chromium, cobalt, iron, magnesium, molybdenum, potassium, selenium, silver, sodium, and vanadium utilizing Test Method 6010B;
- 76 soil samples were analyzed for beryllium utilizing Test Method 6010B;
- 95 soil samples were analyzed for nickel utilizing Test Method 6010B;
- 77 soil samples were analyzed for mercury utilizing Test Method 7471A; and
- 68 soil samples were analyzed for cyanide utilizing Test Method 9010B.

The 226 soil samples collected during the second round of sampling were retained for laboratory analyses for arsenic, cadmium, and lead utilizing Test Method 6010B. In addition, other analyses were completed for selected limited sample sets, as follows:

- 69 soil samples were analyzed for aluminum, barium, cobalt, molybdenum, and silver utilizing Test Method 6010B;
- 157 soil samples were analyzed for copper, manganese, nickel, and zinc utilizing Test Method 6010B;
- 199 soil samples were analyzed for iron and magnesium utilizing Test Method 6010B;
- 96 soil samples were analyzed for chromium utilizing Test Method 6010B;
- 27 soil samples were analyzed for beryllium utilizing Test Method 6010B;
- 27 soil samples were analyzed for antimony utilizing Test Method 6010B; and
- 27 soil samples were analyzed for mercury utilizing Test Method 7471A.



During the two (before and after the July 2006 flooding) stream sediment sampling events, nine samples were retained for laboratory analyses for arsenic, beryllium, cadmium, copper, manganese, nickel, zinc, and lead utilizing Test Method 6010B. In addition, other analyses were completed for selected limited sample sets, as follows:

- Two samples collected before the July 2006 flood event were analyzed for antimony utilizing Test Method 6010B;
- Two samples collected before the July 2006 flood event were analyzed for mercury utilizing Test Method 7471A;
- Three samples collected before the July 2006 flood event were analyzed for cyanide utilizing Test Method 9010B; and
- Five samples collected after the July 2006 flood event, were analyzed for aluminum, antimony, barium, boron, calcium, chromium, cobalt, iron, magnesium, molybdenum, potassium, selenium, silver, sodium, thallium, and vanadium utilizing Test Method 6010B.

During subsurface soil investigation activities at the site, a total of nine soil borings were drilled and sampled at 1-, 5-, and 10-foot intervals for a total of 30 samples, including 3 duplicates that were submitted to a fixed-based laboratory for the following analyses:

- Antimony, arsenic, beryllium, cadmium, copper, lead, manganese, nickel, and zinc utilizing Test Method 6010B;
- Mercury utilizing Test Method 7471A;
- Cyanide utilizing Test Method 9010B; and
- Soil pH utilizing Test Method 9040/9045.

#### *6.3.8.2.1 Surface Soils*

A total of 214 surface soil samples were retained for laboratory analyses of metals and cyanide. The analytical results presented in Table 8 indicated exceedances of both the R-SRLs and/or minimum GPLs for arsenic, cadmium and lead at soil sampling locations at and in the vicinity of the Site. Exceedances of the R-SRLs were also indicated for copper, manganese, vanadium, and zinc at the same soil sampling locations. In addition, similar to the EDXRF results, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

*Arsenic* concentrations were recorded at a maximum of 310 mg/kg and exceeded the R-SRL of 10 mg/kg in 73 of the 205 samples analyzed. In addition, 2 of these 73 samples have arsenic



concentrations greater than or equal to the minimum GPL of 290 mg/kg. **Note:** In all but one case where arsenic exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Cadmium** concentrations were recorded at a maximum of 220 mg/kg and exceeded minimum GPL of 29 mg/kg and the R-SRL of 39 mg/kg in eight of the 205 samples analyzed. An additional six samples have cadmium concentrations greater than or equal to the minimum GPL of 29 mg/kg. **Note:** In all cases where cadmium exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Copper** concentrations ranged from 13 mg/kg to 6,500 mg/kg and exceeded the R-SRL of 3,100 mg/kg in nine of the 168 samples analyzed. There is no minimum GPL established for copper. **Note:** In all cases where copper exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Manganese** concentrations ranged from 120 mg/kg to 34,000 mg/kg and exceeded the R-SRL of 3,300 mg/kg in 16 of the 167 samples analyzed. There is no minimum GPL established for manganese. **Note:** In all cases where manganese exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Vanadium** concentrations ranged from 5.3 mg/kg to 130 mg/kg and exceeded the R-SRL of 78 mg/kg in two of the 27 samples analyzed. There is no minimum GPL established for vanadium. **Note:** In all cases where vanadium exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Zinc** concentrations ranged from 48 mg/kg to 58,000 mg/kg and exceeded the R-SRL of 23,000 mg/kg in six of the 168 samples analyzed. There is no minimum GPL established for zinc. **Note:** In all cases where zinc exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Lead** concentrations ranged from 31 to 59,000 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 87 of the 205 samples analyzed. An additional 41 samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg.

#### 6.3.8.2.2 Soils at 6 Inches

At the sampled depth of 6 inches below ground surface, a total of 63 soil samples were retained for laboratory analyses of metals. The analytical results presented in Table 8 indicated exceedances of both the R-SRL and/or minimum GPL for lead at soil sampling locations at and in the vicinity of the Site. Exceedances of the R-SRLs were also indicated for arsenic at the same soil sampling locations.



In addition, similar to the EDXRF results, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

**Arsenic** concentrations were recorded at a maximum of 100 mg/kg and exceeded the R-SRL of 10 mg/kg in 11 of the 63 samples analyzed. **Note:** In all cases where arsenic exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Lead** concentrations ranged from 38 to 5,600 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 12 of the 63 samples analyzed. An additional six samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg.

#### 6.3.8.2.3 Soils at 12 Inches

At the sampled depth of 12 inches below ground surface, a total of 44 samples were retained for laboratory analyses of metals. The analytical results presented in Table 8 indicated exceedances of both the R-SRLs and/or minimum GPLs for cadmium and lead at soil sampling locations at and in the vicinity of the Site. Exceedances of the R-SRLs were also indicated for arsenic, manganese, and zinc at the same soil sampling locations. In addition, similar to the EDXRF results, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants.

**Cadmium** concentrations were recorded at a maximum of 200 mg/kg and exceeded minimum GPL of 29 mg/kg and the R-SRL of 39 mg/kg in one of the 44 samples analyzed. An additional 1 sample has a cadmium concentration greater than or equal to the minimum GPL of 29 mg/kg. **Note:** In all cases where cadmium exceeded the R-SRL and/or minimum GPL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Arsenic** concentrations were recorded at a maximum of 240 mg/kg and exceeded the R-SRL of 10 mg/kg in nine of the 44 samples analyzed. **Note:** In all cases where arsenic exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

**Manganese** concentrations ranged from 260 mg/kg to 4,100 mg/kg and exceeded the R-SRL of 3,300 mg/kg in one of the 31 samples analyzed. There is no minimum GPL established for manganese. **Note:** In all cases where manganese exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or the minimum GPL.

**Zinc** concentrations ranged from 69 mg/kg to 65,000 mg/kg and exceeded the R-SRL of 23,000 mg/kg in two of the 31 samples analyzed. There is no minimum GPL established for zinc.



**Note:** In all cases where zinc exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL.

**Lead** concentrations ranged from 49 to 19,000 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in 11 of the 44 samples analyzed. An additional four samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg.

#### 6.3.8.2.4 Soils at 24 Inches

At the sampled depth of 24 inches below ground surface, a total of nine samples were retained for laboratory analyses of metals. The analytical results presented in Table 8 indicated exceedances of both the R-SRL and/or minimum GPL of lead at soil sampling locations at and in the vicinity of the Site. Lead concentrations ranged from 8.9 to 430 mg/kg and exceeded the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in one of the nine samples collected. An additional two samples have lead concentrations greater than or equal to the minimum GPL of 290 mg/kg.

#### 6.3.8.3 Subsurface Soil Samples from Soil Borings

A total of nine subsurface borings were sampled at 1-, 5-, and 10-foot increments for a total of 30 samples, including 3 duplicates that were analyzed for soil pH, metals and cyanide. The analytical results presented in Table 9 reported exceedances of both the minimum GPLs and R-SRLs for cadmium and lead at certain sampled depths. In addition, exceedances of the R-SRLs were also reported for arsenic, copper, manganese, and zinc at certain sampled depths. The pH in soil was neutral ranging from 5.4 to 8.5.

**Arsenic** concentrations ranged from <5.0 mg/kg to 140 mg/kg and exceeded the R-SRL of 10 mg/kg in five samples. The deepest extent of arsenic concentrations that exceeded screening levels was in Boring KB3 at the 5-foot depth, where the reported concentration was 140 mg/kg.

**Cadmium** concentrations ranged from <1.0 mg/kg to 130 mg/kg and exceeded the both the minimum GPL of 29 mg/kg and the R-SRL of 38 mg/kg in two samples. The deepest extent of cadmium concentrations that exceeded screening levels was in Boring KB3 at the 5-foot depth, where the reported concentration was 81 mg/kg.

**Copper** concentrations ranged from 7.2 mg/kg to 5,600 mg/kg and exceeded the R-SRL of 3,100 mg/kg in one sample. The deepest extent of copper concentrations that exceeded screening levels was in Boring KW2 at the 1-foot depth, where the reported concentration was 5,600 mg/kg.

**Manganese** concentrations ranged from 280 mg/kg to 11,000 mg/kg and exceeded the R-SRL of 3,300 mg/kg in two samples. The deepest extent of manganese concentrations that exceeded



screening levels was in Boring KW2 at the 1-foot depth, where the reported concentration was 11,000 mg/kg.

**Zinc** concentrations ranged from 31 mg/kg to 45,000 mg/kg and exceeded the R-SRL of 23,000 mg/kg in two samples. The deepest extent of zinc concentrations that exceeded screening levels was in Boring KB3 at the 5-foot depth, where the reported concentration was 29,000 mg/kg.

**Lead** concentrations ranged from 12 to 26,000 mg/kg and exceeded both the minimum GPL of 290 mg/kg and the R-SRL of 400 mg/kg in seven samples. The deepest extent of lead concentrations that exceeded screening levels was in Boring KB3 at the 5-foot depth, where the reported concentration was 22,000 mg/kg. In addition, lead is the most frequently detected and most prevalent contaminant that exceeded action levels relative to the other contaminants. Its results are posted on a map of the study area (Figure 10).

### 6.3.9 Correlation of EDXRF and Fixed-base Soil Sample Results

Since lead is the most frequently detected and most prevalent contaminant at the Site that exceeded screening levels relative to the other contaminants, the EDXRF lead results were used to characterize site soils. There generally is a statistically significant correlation between lead results by EDXRF and lead results by EPA Method 6010B. Analysis for lead by EDXRF typically generates more conservative results for lead than fixed-base laboratory methods and is less expensive than fixed-base laboratory methods for the analysis of large number of specimens. Previous applications of this screening methodology at similar sites have confirmed that the EDXRF is acceptable for screening soil samples for lead contamination. In addition, URS and Transwest reviewed the EDXRF sample preparation methodology and instrument calibration procedures to establish an acceptable correlation between EDXRF and fixed-base laboratory results (EPA Method 6010B) that supports use of the EDXRF to fully characterize the extent of lead contamination at the Site. However, since EDXRF is a field screening method, the usefulness of the performance-based EDXRF data for compliance with the regulatory standard for lead needed to be evaluated by comparing the EDXRF results to the 6010B analytical method results for the same samples. A quantitative comparison correlation of site data was completed for lead to evaluate if a statistically significant relationship exists between EDXRF data and 6010B data for soil samples collected at the Site. URS also conducted quantitative comparisons for manganese and cadmium, because the EDXRF results of these two metals showed high frequencies of exceedances of screening levels, as well as the availability of the most corresponding fixed-based laboratory results. A quantitative comparison correlation could not be completed for the arsenic data since majority of the EDXRF data was determined to be unusable. However, a direct comparison of the valid non-detect EDXRF results were compared to the corresponding 6010B results.



### 6.3.9.1 Comparison of Lead EDXRF to Method 6010B

In comparing the EDXRF and 6010B data for lead, approximately 13.7 percent of the soil samples (330 samples) with EDXRF results were submitted to a fixed-base laboratory for 6010B analysis. A total of 200 samples indicated EDXRF lead results less than the R-SRL of 400 mg/kg, and the corresponding 6010B results indicated that 11 of those samples (5%) contained lead above 400 mg/kg. A total of 124 soil samples indicated EDXRF lead results equal to or greater than 400 mg/kg, and corresponding 6010B results that 24 of those samples (over 15%) contained lead less than 400 mg/kg. This confirms that the EDXRF typically generates more conservative results for lead than the 6010B results.

A regression analysis was also completed to compare the EDXRF lead results to the 6010B to determine the regression coefficient ( $R^2$ ). The EPA-approved methodology for EDXRF requires an  $R^2$  of at least 0.70 (EPA, 1998) for data to be deemed usable for compliance screening purposes. Three separate regression analyses were completed for lead (Figure 11), as follows:

- for EDXRF lead results < 400 mg/kg the calculated  $R^2$  is 0.754;
- for EDXRF lead results  $\geq$  400 mg/kg the calculated  $R^2$  is 0.935; and
- for all EDXRF lead results the calculated  $R^2$  is 0.941.

The results of the regression analysis indicate a positive correlation between the two analytical methods, and the correlations are statistically significant. Thus, it is acceptable to use the EDXRF data to characterize the extent of lead contamination at the Site to residential soil remediation levels.

### 6.3.9.2 Comparison of Manganese EDXRF to Method 6010B

In comparing the EDXRF and 6010B data for manganese, approximately 10 percent of the soil samples (260 samples) with EDXRF results were submitted to a fixed-base laboratory for 6010B analysis. The comparison of the 6010B manganese results with the corresponding EDXRF results is provided in Table 10. A total of 229 samples indicated EDXRF manganese results less than the R-SRL of 3,300 mg/kg, and the corresponding 6010B results indicated that no samples contained manganese above 3,300 mg/kg. A total of 31 soil samples indicated EDXRF manganese results equal to or greater than 3,300 mg/kg, and the corresponding 6010B results indicated that 14 of those samples contained manganese less than 3,300 mg/kg. This confirms that the EDXRF typically generates more conservative results for manganese than the 6010B results.

The results of the regression analysis completed for manganese (Figure 12) indicated that for all EDXRF results the  $R^2$  is 0.702 that meets the EPA minimum requirements (EPA, 1998). However, for EDXRF results less than or equal to 3,300 mg/kg, the  $R^2$  is 0.260, which indicates a negative



correlation between the two analytical methods. Therefore, it may not be appropriate to use the EDXRF data to characterize the extent of manganese contamination at the Site to residential soil remediation levels.

### ***6.3.9.3 Comparison of Cadmium EDXRF to Method 6010B***

In comparing the EDXRF and 6010B data for cadmium, approximately 13 percent of the soil samples (338 samples) with EDXRF results were submitted to a fixed-base laboratory for 6010B analysis. A total of 325 samples indicated EDXRF cadmium results less than the R-SRL of 39 mg/kg, and the corresponding 6010B results indicated that no samples contained cadmium above 39 mg/kg. A total of 13 soil samples indicated EDXRF cadmium results equal to or greater than 39 mg/kg, and the corresponding 6010B results indicated that four of those samples contained cadmium less than 39 mg/kg. In addition, except in eight instances, all of the EDXRF cadmium results were higher than the corresponding 6010B results. This confirms that the EDXRF typically generates more conservative results for cadmium than the 6010B results.

The results of the regression analysis completed for cadmium (Figure 13) indicated that for all EDXRF results, the  $R^2$  is 0.939 that meets the EPA minimum requirements (EPA, 1998). **Note:** Half of the detection limit was used for cadmium concentration below the method reporting limit. In addition, since there were a large number of non-detects in the EDXRF data set, a second regression analysis was completed for the EDXRF results that reported cadmium above the detection limit and corresponding 6010B results. The result of the second analysis also calculated an  $R^2$  of 0.939. These results indicate a positive correlation between the two analytical methods, and the correlations are statistically significant. Thus, it is acceptable to use the EDXRF data to characterize the extent of cadmium contamination at the Site to residential soil remediation levels.

### ***6.3.9.4 Comparison of Arsenic EDXRF to Method 6010B***

In every instance, where the EDXRF results reported a concentration of arsenic at less than the instrument's reporting limit of 10 mg/kg, the corresponding 6010B results also showed arsenic at less than its method detection limit. This seems to indicate that the <10 mg/kg EDXRF data for arsenic is usable.



## 6.3.10 Variation of Metals in surface and subsurface Soils

### 6.3.10.1 Lead

The highest reported concentrations of lead and the largest range of lead concentrations in surficial soils are within the source area parcels and the immediately surrounding area, bounded by Klondyke Road to the east, Aravaipa Creek to the southwest, and Laurel Creek to the northwest. Concentrations of lead within this area range from below the R-SRL of 400 mg/kg to 50,000 mg/kg. East of the WQARF site, lead concentrations were reported at a maximum of 18,000 mg/kg at a point northeast of the private residence in parcel 110-47-006 where tailing-like material was observed on the hillside. The tailing-like material on the private property is believed to come from the Dogwater Mine and represents a historical attempt at processing ore from that mine (Schnell, 2007). Those materials are unrelated to the historical operations at the Klondyke Site. Northwest of the WQARF site, lead concentrations exceeding the R-SRL were also reported along the banks of Laurel Creek, on a stream terrace just below the Laurel Creek-Aravaipa Creek confluence, and in vegetated areas near Klondyke Road north of the WQARF site. Across the full study area, 794 sample results reported lead exceeding the 400 mg/kg R-SRL and 869 samples reported lead exceeding the 290 mg/kg minimum GPL in surface soils. Outside of the source area parcels, approximately 65 acres covering ten parcels are impacted by lead concentrations exceeding the R-SRL in surficial soils. The ten parcels impacted include 110-47-001b, 110-47-001g, 110-47-001h, 110-47-001i, 110-47-001k, 110-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, and 110-47-006.

At the 6-inch depth interval the highest reported lead concentration at 26,000 mg/kg was from a sample collected in the mill yard area within the WQARF site. Outside of the WQARF site, high lead concentrations at 6-inch depth were reported northeast of the private residence where tailing-like material was observed, along Laurel Creek, and near the Laurel Creek-Aravaipa Creek confluence. Across the full study area, 180 sample results reported lead above the R-SRL and 234 samples have lead concentrations greater than or equal to the minimum GPL. Approximately 40 acres of land throughout eight parcels outside the source area parcels are impacted by lead concentrations exceeding the R-SRL at a depth of 6 inches. The eight parcels include 110-47-001g, 110-47-001h, 110-47-001i, 110-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, and 110-47-006.

At the 12-inch depth interval, the highest reported lead concentration was from a sample northeast of parcel 110-47-006 where tailing-like material was observed. Lead concentrations exceeding the R-SRL were also reported along Laurel Creek and near the Laurel Creek-Aravaipa Creek confluence. In addition, several locations in the northern portion of the study area also reported concentrations of lead above the R-SRL. Across the full study area, 83 sample results reported lead above the R-SRL and 115 samples have lead concentrations greater than or equal to the minimum



GPL. Approximately 18 acres of land throughout seven parcels outside the source area parcels are impacted by lead concentrations exceeding the R-SRL at a depth of 12 inches. The seven parcels include 110-47-001g, 110-47-001i, 110-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, and 110-47-006.

At the 24-inch depth interval, the highest reported lead concentration was from a sample collected just below the Laurel Creek-Aravaipa Creek confluence. Lead concentrations exceeding the R-SRL were also reported for samples along Laurel Creek and two isolated locations north of Laurel Creek. Across the full study area, 18 sample results reported lead above the R-SRL and 19 samples have lead concentrations greater than or equal to the minimum GPL. Approximately 16 acres of land throughout five parcels outside the source area parcels are impacted by lead concentrations exceeding the R-SRL at a depth of 24 inches.

Subsurface soil boring sampling results within the source area parcels indicated that lead contamination in the vicinity of the borings generally extends below ground surface to at least one foot. Samples collected at the five foot interval showed low lead concentrations with the exception of one sample at KB3 that was located in a thick tailings outwash west of the Lower Tailings Pile. Samples collected at the ten foot interval showed low lead concentrations well below the R-SRL and minimum GPL.

#### **6.3.10.2 Arsenic**

When evaluating the variation of arsenic in soil, only the <10 mg/kg results from the EDXRF data and all of the results of the 6010B data were used. In surficial soils the distribution of arsenic, based on the limited data, was similar to the distribution of lead (Figure 14). In addition, at the 6-, and 12-inch sampled depths, the distribution of arsenic, based on the limited results, were also similar to the distribution of lead at the same depths (Figures 15 and 16). However, at the 24-inch sampled depth, arsenic was not reported above the R-SRL of 10 mg/kg (Figure 17).

Similar to distribution of lead, subsurface soil boring sampling results within the source area parcels indicated that arsenic contamination in the vicinity of the borings generally extends below ground surface to at least one foot. Samples collected at the five foot interval also showed low arsenic concentrations with the exception of one sample at KB3 that was located in a thick tailings outwash west of the Lower Tailings Pile. Samples collected at the ten foot interval showed arsenic concentrations below the laboratory reporting limit.



### **6.3.10.3 Other Metals**

In surficial soils across the full study area antimony, cadmium, copper, manganese, mercury, and zinc were detected at some soil sampling locations at concentrations exceeding the R-SRLs and/or the minimum GPLs. The highest concentrations of these metals were reported within the WQARF site in close proximity to the mill yard. In addition, higher concentrations of antimony, cadmium, and zinc were also reported northeast of the private residence in parcel 110-47-006 where tailing-like material was observed. For the EDXRF mercury results that exceeded the R-SRLs and/or minimum GPLs, the corresponding 7471A results were either below laboratory reporting limits or below the R-SRL or minimum GPL. In all cases, the distributions of these metals were well within the boundary of the lateral distribution of lead concentrations exceeding the R-SRL and/or minimum GPL.

In shallow surface soils from 6 to 24 inches, bgs the highest concentrations of antimony, cadmium, copper, manganese, mercury, and zinc were generally found within the source area parcels and northeast of the private residence in parcel 110-47-006 where tailing-like material was observed. At deeper sampled depths, concentrations of cadmium, copper, manganese, and zinc, generally begin to decrease where, at the 24 inch depth, their concentrations are below the R-SRLs and/or minimum GPLs. Antimony and mercury concentrations appear to fluctuate at different depths. However, as previously stated, for the EDXRF mercury results that exceeded the R-SRLs and/or minimum GPLs, the corresponding 7471A results were either below laboratory reporting limits or below the R-SRL or minimum GPL. In all cases, the distributions of these metals were well within the boundary of the lateral distribution of lead concentrations exceeding the R-SRL and/or minimum GPL.

Similar to distribution of lead and arsenic, subsurface soil boring sampling results within the source area parcels indicated that cadmium, copper, manganese, and zinc contamination in the vicinity of the borings generally extends below ground surface to at least one foot. Samples collected at the five foot interval also showed low concentrations of these metals with the exception of one sample at KB3, located in a thick tailings outwash west of the Lower Tailings Pile, which indicated concentrations of cadmium and zinc that exceeded the R-SRLs and/or minimum GPLs. Samples collected at the ten foot interval showed metal concentrations below the laboratory reporting limits or below respective R-SRLs and/or minimum GPLs.

## **6.4 FIELD QUALITY ASSURANCE AND QUALITY CONTROL**

The following describes the field quality assurance and quality control for surface soil, subsurface soil, surface water, and stream sediment samples.



### **6.4.1 Field Equipment Blanks**

Field equipment blanks were not collected for this task. Soil samples were collected to characterize the extent of lead and other heavy metal contamination and were collected with tools decontaminated after each use.

### **6.4.2 Field Duplicates**

Field duplicate samples were collected and analyzed to evaluate sampling and analytical precision. The precision goal for field duplicate analyses was plus or minus a 35 relative percent difference (RPD). Field duplicates were collected at a frequency of approximately 10 percent of the primary samples collected. The duplicate samples were analyzed for the same metals as primary samples.

### **6.4.3 Sampling Coordinates**

A base station was selected and surveyed at the Site using a Leica GPS. Sampling locations were entered into the backpack unit that referenced the base station for location. Locations were referenced to the Arizona State Plane Coordinate System for northing and easting with an accuracy of plus or minus 3 to 10 centimeters (cm). Additional locations from the expanded grid that were not directly entered into the system were tied into the surveyed origin with measured distances to the nearest logged location.

### **6.4.4 Sample Preparation and Chains of Custody**

In the field, each sample container was marked with the sampling location number, and the date and time of sample collection. Sample containers were securely packed in a cooler with ice in preparation for delivery to the laboratory or submittal to the onsite mobile laboratory.

All samples submitted to the analytical laboratory for screening or analyses were completed under COC. A COC form supplied by the laboratory was completed for each day of sampling. The information recorded on the collected samples in the COC form included the sampling date and time, sample identification number, requested analytes and methods, and sampler's name. The field supervisor maintained custody of the samples until they were relinquished to the laboratory or courier. The laboratory provided a copy of the completed COC form along with the final report of results.

### **6.4.5 Field Documentation**

The field supervisor directed sampling activities and was responsible for maintaining the following field documentation:



- A geologic log for each boring describing and classifying the soil and indicating the samples submitted for analyses;
- the sample container labels and COC forms;
- health and safety documentation as required by the Health and Safety Plan;
- a soil sampling data sheet to record the following:
  - ✓ sampling date and time,
  - ✓ boring number, depth of sample,
  - ✓ sample identification as written on container labels, with blind quality control (QC) samples identified and referenced to the respective primary sample or collection location,
  - ✓ QC type (P0 = primary sample, D1 = duplicate sample, or EB = field equipment blank), and
  - ✓ other observations or comments such as sample odor or sample color; and
- a daily field report sheet that records field activities and pertinent data that are not included on the other forms described above, including general site conditions, daily weather, arrival and departure of subcontractors and visitors, equipment used onsite, equipment problems, handling and disposal of waste material, and other relevant information.

#### **6.4.6 Investigation-Derived Waste**

Investigation derived waste (IDW) generated during field activities was handled in accordance with procedures as described in the Work Plan (URS, 2006). This material includes soil cuttings, decontamination water, disposable sampling equipment, and personal protective equipment.

All cuttings and waste soil generated during hand auguring and sampling were replaced in the soil boring at the sampling location. Continuous core generated during drilling of the four monitor wells and five deep soil borings was placed in 55-gallon drums and stored onsite pending the receipt and review of analytical results to verify the core was non-hazardous. When the core material was confirmed as non-hazardous the material in drums was emptied onto the tailings piles.

Disposable sampling equipment and PPE were placed in trash bags and disposed as solid waste in plastic garbage bags in accordance with applicable regulations. Water generated by decontamination activities was contained onsite and discharged to the surface of the Lower Tailings Pile at the completion of field activities.



### **6.4.7 Data Verification**

Data verification is the procedure of reviewing data against a known set of criteria to verify data validity prior to its use. Laboratory data collected during this investigation were subjected to verification to assess for bias, and reviewed for completeness, representativeness, and applicable levels of precision and accuracy.

A data verification memorandum for soil and sediment sample analyses is included in Appendix E. With the exception of the EDXRF results for arsenic the results for samples collected by URS during characterization activities were found to be of good quality and useable for their intended purpose. Surface Water and Stream Sediment Characterization

## **6.5 TOPOGRAPHY AND FLOODPLAIN MAPPING**

### **6.5.1 2002 Geomorphological Report**

The 2002 Geomorphological Report completed by JE Fuller Hydrology & Geomorphology, Inc. (Fuller, 2002) summarizes the results of an investigation of the potential for lateral channel erosion of Aravaipa Creek at the Laurel Canyon confluence, adjacent to the Klondyke tailings piles. Fuller first used aerial photographs to identify areas that required further investigation. Field observations then were conducted to identify the existing channel and floodplain conditions, identify areas of channel erosion, and verify aerial photograph interpretations. Field visits were conducted in Aravaipa Creek to observe channel patterns using the Rosgen Stream Classifications System (1996), channel alignment, floodplain deposition, cut banks, erosion from site runoff, wind erosion, high water marks, bank vegetation, and floodplain obstructions in Aravaipa Creek. The Laurel Creek field visit was conducted to observe alluvial fan movement, channelization, channel lateral movement, debris flows and cut banks.

### **6.5.2 2006 Geomorphological Report**

The 2006 Aravaipa Creek Erosion Analysis was prepared by Fuller to summarize surface water erosion in the area of the Klondyke tailings during the July 2006 flood event. The objectives of this study were to evaluate the impact of the 2006 flood event on the floodplain and stream channel and to evaluate the viability of the proposed ERA for the tailings sites and existing channel conditions. Fuller conducted a field reconnaissance to investigate the channel and bank positions, bank materials, high water marks and direction of flow in Aravaipa and Laurel Creeks, along with an unnamed wash located northeast of the tailings pile. The field reconnaissance was also used to generate a new map of the geomorphic surfaces using the new topographic data and 2006 aerial



photos. Fuller developed a map of geomorphic surfaces to identify the active alluvial fan, active channels, riverine floodplains, and mountain slopes (Fuller, 2006).

### **6.5.3 2007 Floodplain Analysis Report**

The purpose of this study was to summarize the hydrologic and hydraulic analysis in response to the ERA at the Site. As part of the hydrologic study, peak discharges were developed along Aravaipa Creek and Laurel Creek based on USGS flood frequency analysis Bulletin 17B (USGS, 2000) and USGS regression equations, respectively. The hydraulic analyses included HEC-RAS models to estimate surface elevations for different storm events and delineate floodplains for the different storm events (URS, 2007).

#### **6.5.3.1 Data Collection and Review**

The hydrologic study of the Site and vicinity included a literature review of the Flood Insurance Rate Maps (FIRM) Panel 0600B, dated 1984 and the Flood Insurance Report for Graham County, Arizona, dated June 4, 1984. URS reviewed the SCS (1998) report and the two Fuller reports (Fuller 2002; 2006). USGS stream gage 09473000, located 25 miles north of the Site on Aravaipa Creek, provided 56 years of data for analysis. A geohydrology assessment of Aravaipa Canyon also was reviewed (Fuller, 2000).

Hydraulic analyses for Aravaipa Creek and Laurel Creek also were conducted by URS. A field reconnaissance investigation also was conducted in January 2007 to help determine the Manning's  $n$  values to be used in the analysis. A HEC-RAS model was developed to estimate surface water elevations for different storm events, floodplains were delineated for different storm events, and the HEC-RAS model and a floodplain map were used to evaluate the effect of ERA alternatives for the 100 year floodplain

#### **6.5.3.2 Hydrologic and Hydraulic Analysis**

Peak discharges at the Site were estimated using 56 years of discharge data collected from USGS Gage 09473000 on Aravaipa Creek, 25 miles north of the Site, to calculate the 100-year peak flow event. Peak discharges at the Site were calculated using the ratio between the drainage area at the site to the drainage area at the gage. Watersheds were delineated using Watershed Modeling System (EMS-I, 2001) software and adjustments made following the USGS topographic map.

A USGS Gage was not available for Laurel Creek, so the USGS Regression Equations for Arizona were used to calculate the peak discharges of Laurel Creek.



The FIRM Panel 0600B for Graham County, 1984, was used to determine in which flood zone the Aravaipa and Laurel Canyon Creeks were designated. Field reconnaissance and aerial imagery were used to estimate Manning's 'n' values for Aravaipa Creek and Laurel Creek. Kenney Aerial Mapping, Inc. provided aerial topographic mapping at 1-foot intervals. Stream cross-sections for Aravaipa Creek and Laurel Creek were generated using HEC-GeoRAS 4.1.1. (U.S. Army Corps of Engineers [USACE], 2006).

Water surface elevations for the 10-, 25-, 50-, and 100-year storm were computed using the USACE HEC-RAS program (USACE, 2005). The water surface elevation for the 100-year event for Laurel Canyon Creek was computed for four scenarios: 1) The left levee fails and the right levee stays in place. 2) The right levee fails and the left levee stays in place. 3) Both levees fail. 4) Both levees stay in place.

The Aravaipa Creek drainage area at USGS gage 09474300 is 537 square miles. The peak discharges calculated for the various storm events were: 11,780 cfs for the 10-year storm event; 17,690 cfs for the 25-year event; 23,020 cfs for the 50-year event; and 29,200 cfs for the 100-year event.

The Aravaipa Creek drainage area at the Site is 331.9 square miles. The peak discharges calculated for the various storm events, using a ratio between the gaged and ungaged sites, were: 9,261 cfs; 13,907 cfs; 18,098 cfs; and 22,956 cfs for the 10-, 25-, 50-, and 100-year storm events, respectively.

The drainage area for Laurel Creek at the Site is 7.37 square miles. The peak discharges calculated for the various storm events using the USGS Regression Equation for Arizona were: 1,110 cfs; 1,750 cfs; 2,340 cfs; and 3,000 cfs for the 10-, 25-, 50-, and 100-year storm events, respectively (URS, 2007).

The field reconnaissance helped to estimate the Manning's "n" value by classifying the channel material as firm soil with coarse sand, fine to coarse gravels, and cobbles. The Manning's "n" value ranges from 0.026 to 0.028 (unitless) for the study reaches. Kenney Aerial Mapping, Inc. prepared aerial topographic maps for Aravaipa Creek and Laurel Creek near the Site and estimated the average slope of the stream channels as 0.0158 ft/ft and 0.0066 ft/ft, respectively.

The floodplain delineations indicate that both the Aravaipa Creek and Laurel Creek 10-, 25-, 50-, and 100-year floodplains affect both the Upper and Lower Tailings Piles. Scour analysis and erosion protection to protect the tailings piles from the sheet flow were considered in the flood protection designed for the Upper Tailings Pile were considered in the 2006 Geomorphological Report.

Results of the Floodplain Analysis showed the levees (embankments) currently constructed along Laurel Creek do not meet the requirements as stated in 44 Code of Federal Regulations (CFR) 65.10



(URS, 2004). Water elevations computed for the four scenarios resulted in the conclusion that Scenario 1, the left levee failed and the right levee remained in place, was the worst scenario for the Site, resulting in the greatest damage to the tailings piles.

#### **6.5.4 2002 Geomorphological Report**

In 2002, Fuller conducted a geomorphological study of Aravaipa Creek near the Site to investigate the potential for lateral channel erosion of Aravaipa Creek at the Laurel Creek confluence, adjacent to the Klondyke tailings piles (Fuller, 2002). A field visit of Aravaipa Creek, Laurel Creek, and the Site was conducted to observe geomorphological features as described above.

According to Fuller, Aravaipa Creek was classified as a D4 channel by the Rosgen Stream Classification System due to the creek's high flow velocity, high erodibility, and sediment rates (Fuller, 2002). The channel alignment is at a 30-degree angle to the Upper Tailings Pile and is approximately 30 feet from the tailings edge. Wind erosion and Site runoff are two potential causes of erosion of the tailings piles. Surface runoff has caused small channels to form on the tailings piles and has transported sediments to the Aravaipa Creek floodplain and the distal end of the Laurel Creek alluvial fan. Ripple marks at the base of the tailings show potential movement of contaminated soil by wind. Bank vegetation in Aravaipa Creek is minimal, immature and shows little bank stability.

Laurel Creek has a large alluvial fan located upstream from the Klondyke tailings that is susceptible to sediment deposition and erosion, and one bifurcation exists in the main channel of the creek. The creek bed has been manually straightened and levees put into place to prevent lateral movement. Fuller determined that the levees and channel should be expected to erode in future floods (Fuller, 2002). There is evidence that recent flooding has broken out of the engineered channel and flowed towards the west side of the Lower Tailings Pile. Large boulders deposited in the Laurel Creek alluvial fan demonstrate the possibility of future debris flows that could fill the channel with sediment. The creek bed also shows evidence of cut banks above the tailings, and future lateral movement could be expected.

Active lateral erosion should be expected along the primary channel banks of the Aravaipa Creek closest to the tailings site, and active erosion was observed less than 30 feet from the edge of the tailings. According to observed field conditions and a historical review of the site geomorphology, a single moderate flood event could cause the tailings to erode into Aravaipa Creek (Fuller, 2002).



### **6.5.5 2006 Geomorphological Report**

In 2006, Fuller conducted a new study of Aravaipa and Laurel Creeks to evaluate the impact of the 2006 flood event on the floodplain and stream channel and to evaluate the viability of the ERA for the tailings sites and existing channel conditions (Fuller, 2006).

Fuller conducted a field reconnaissance to investigate the changes to channel and bank positions, and generated a new map of the geomorphic surfaces using the new topographic data and 2006 aerial photos. The new map of Aravaipa Creek showed bank widening on the north bank as a result of the 2006 flooding event. Bank material consisted of layered unconsolidated sand and gravel. High water marks showed that Aravaipa Creek overtopped its banks with shallow non-erosive flows. High water marks were observed along the upstream side of the tailings slope and caused a slight scour line. Floodwaters did not contact the tailings pile on the downstream side.

Laurel Creek overtopped its banks in several locations on both sides of the creek bed and had an approximate depth of less than two feet (Fuller, 2006). The water did have enough energy to cause scouring, but there was no evidence of significant erosion of the tailings piles. The flood waters from Laurel Creek entered the Site at Klondyke Road and several places on the western side of the Site.

An unnamed wash that drains a small watershed northeast of the Lower Tailings Pile had high water marks from the 2006 flood. The water marks indicated broad shallow (less than one foot deep) flow across Klondyke Road, which was then collected and conveyed by a low earthen berm and shallow channel along the northeast side of the Lower Tailings Pile. The berm did contain a breach at one location (Fuller, 2006).

## **6.6 SURFACE WATER AND STREAM SEDIMENT SAMPLING RATIONALE**

### **6.6.1 Surface Water**

Aravaipa Creek and Laurel Creek are ephemeral and typically dry at the tailings site. Flows generally occur during winter storms in early spring, and in July and August as a result of summer thunderstorms. Surface water samples were collected when available during a storm or flood event.

### **6.6.2 Stream Sediments**

The rationale for sampling of stream sediments included obtaining cross-sectional lateral profiles of stream sediment conditions at multiple locations across Aravaipa Creek: upstream, adjacent to, and downstream from the tailings piles. These samples were used to evaluate the immediate impact of runoff from the tailings piles on stream sediments. Comparable sampling was conducted across Laurel Creek from its outflow at the end of Laurel Canyon down gradient along the alluvial fan to



the confluence with Aravaipa Creek. These samples were used to evaluate changes in sediment conditions down gradient from Laurel Canyon.

The stream sediments were conducted in two rounds. The initial stream sediment sampling was implemented in March 2006 and completed in May 2006. Following a large storm event in July 2006, additional stream sediment sampling was conducted in October and November 2006 and again in May and October 2007. This was done to assess whether any movement of metals-contaminated tailings material had occurred during the flood and impacted stream sediment conditions.

### **6.6.3 Sample Collection**

#### **6.6.3.1 Surface Water**

Three surface water samples were collected from Aravaipa Creek following a summer flood event in July 2006 (Figure 18). One sample was collected approximately 4.5 miles upstream of the Site, one sample was collected immediately above the confluence with Laurel Creek, and the third sample was collected 2 miles downstream of the Site at the confluence with Stowe Gulch. By the time floodwater had receded enough for access to the Site, flow in Laurel Creek had ceased. Surface water samples were collected as grab samples.

Surface water samples were collected manually using a clean 1-liter plastic bottle held under the water surface with the mouth of the container facing upstream and away from the collector. Water was then transferred to the appropriate laboratory-provided sample containers as designated by the QAPP. Samples for dissolved metals were field-filtered prior to filling the sample container. Sample packaging, preservation, and analytical methods were conducted as stipulated in the QAPP. Samples were submitted to Transwest for analysis.

One surface water sample was collected from Laurel Creek during a storm event on July 23, 2008. Because of the remote location and ephemeral nature of flow events in the small drainage area of Laurel Creek, URS enlisted the aid of Klondyke area resident Virginia Schnell to collect a grab sample of flow from the creek. The sample was collected in a clean-1-gallon plastic container, unfiltered with no preservative. When informed of the sample collection, URS picked up the sample and submitted it for analysis for total metals.

#### **6.6.3.2 Stream Sediment**

##### **6.6.3.2.1 Initial Sampling**

URS sampled stream sediment at intervals of approximately 50 ft along three cross sections that traverse perpendicularly across Aravaipa Creek channel, and five cross sections that extend across



Laurel Creek channel (Figure 19). A total of 38 stream sediment samples, including 2 duplicate samples were collected for analysis. Stream sediment was sampled at 0 to 3 inches bgs to characterize stream sediment conditions upstream, adjacent to, and downstream from the site.

#### **6.6.3.2.2 Additional Sampling**

Following the flood event in July 2006, additional stream sediment samples were collected at Aravaipa Creek and Laurel Creek channels to evaluate any changes that may have occurred as a result of the flooding event. Sampling intervals were approximately 50 feet extending along three cross sections across Aravaipa Creek channel and two cross sections across Laurel Creek channel. A total of 35 stream sediment samples were collected, including 2 duplicate samples (Figure 19).

#### **6.6.3.3 Stream Sediment Sample Collection Techniques in Aravaipa and Laurel Creeks**

Sediment samples were collected using a decontaminated stainless steel spoon and placed in a clean 4-ounce glass jar. The samples were examined to remove rocks, organic matter and other foreign material. The jars were tightly sealed with a lid, labeled, and submitted to the fixed-base analytical laboratory for screening analysis of total metals using the EDXRF. A total of 35 stream sediment samples were collected, including 2 duplicate samples for analysis.

### **6.6.4 Analytical Methods**

#### **6.6.4.1 Surface Water**

Three surface water samples collected from Aravaipa Creek were analyzed by Transwest for 13 priority pollutant total and dissolved metals by EPA Methods 200.7, 200.8 and 200.9. Samples also were analyzed for alkalinity by EPA Method SM2320B; calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) by EPA Methods 200.7 and 200.8; chloride, fluoride and sulfate by EPA Method 300; cyanide by EPA Method SM4500-CN C,E; and nitrate-nitrite by EPA Method 353.2.

The sample collected from Laurel Creek was analyzed for 13 priority pollutant total metals by EPA Methods 200.7, 200.8 and 200.9. Because the sample was collected as a grab sample by a resident, the sample was not field filtered or preserved in the field. It was several days until the sample was delivered to the laboratory and URS did not request that the sample be filtered and analyzed for dissolved metals because it might not be representative of field conditions after that time period.

#### **6.6.4.2 Stream Sediments**

Sediment samples were screened for metals by EDXRF using the same instrument either in a mobile field laboratory or at the fixed-base laboratory. Analytes reported by EDXRF analysis included 10



total metals: antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), and zinc (Zn). Samples sent to a laboratory were analyzed for 8 of those metals (excluding antimony and mercury) by EPA Method 6010B/7471A. The 38 samples collected during the initial sampling event were analyzed onsite at a mobile laboratory. The 35 samples collected during the additional sampling event were analyzed at Transwest's fixed-base laboratory by the same methodology and equipment.

Sample packaging, preservation, and analytical methods were conducted as stipulated in the Quality Assurance Project Plan (QAPP). Samples were submitted to Transwest in Phoenix, Arizona for analysis. Transwest is an Arizona-licensed analytical laboratory (ADHS License No. AZ0133). Analytical methods were performed in accordance with EPA document *SW-846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (EPA, 1994).

## **6.6.5 Results of Surface Water Sampling**

### **6.6.5.1 Aravaipa Creek**

Three surface water samples were collected in August 2006 following a large storm event (Figure 18). The analytical results are presented in Table 12. Surface water analytical reports are provided in Appendix F.

The surface water sample collected approximately 4.5 miles upstream from the Site (AC-SW-1) and the surface water sample collected upstream of the Aravaipa Creek-Laurel Creek confluence (AC-SW-2) contained arsenic, copper, iron, lead, manganese, nickel (AC-SW-1 only), and zinc (AC-SW-2 only) at concentrations above the corresponding laboratory reporting limits. Sample AC-SW-2 contained a concentration of lead at 0.020 mg/L, which exceeds the corresponding ASWQS for full body contact of 0.015 mg/L.

The surface water sample collected approximately 2 miles downstream from the Site (AC-SW-3) contained arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc at concentrations above the corresponding laboratory reporting limits. Sample AC-SW-3 contained concentrations lead at 0.20 mg/L, which exceed the corresponding ASWQS for full body contact of 0.015 mg/L. This sample was collected downstream from where Laurel Creek and Stowe Gulch flow into Aravaipa Creek. Mineralized areas and tailings/waste rock from historical mines are located in both of those drainage areas and may have contributed metals to surface water.

### **6.6.5.2 Laurel Creek**

One surface water sample was collected in July 2008 where Laurel Creek crosses Klondyke Road, just north of the Site (Figure 18). The analytical results are presented in Table 12. Sample Laurel



Creek 072308 contained arsenic and lead at concentrations exceeding the corresponding ASWQS. Copper, iron, manganese, nickel and zinc were detected above the corresponding laboratory reporting limits. Mineralized areas and tailings/waste rock from historical mines are located in the Laurel Creek drainage area and may have contributed metals to surface water.

## **6.6.6 Results of Stream Sediment Sampling**

### **6.6.6.1 Stream Sediment Prior to July 2006 Flooding**

In February 2006, surface stream sediment samples were collected in Aravaipa Creek at three perpendicular cross-sections (Figure 19). A total of 21 samples were collected and analyzed by EDXRF for metals. The analytical results presented in Table 10 indicated that with the exception of arsenic, all other detected metals were at concentrations below the R-SRLs and/or minimum GPLs. Arsenic was detected at two locations just above the detection limit. However, due to the potential of lead interfering with the arsenic results, these two detections are considered invalid. Stream Sediment sample analytical reports are provided in Appendix C.

In March and May 2006 surface stream sediment samples were collected in Laurel Creek at five perpendicular cross-sections (Figure 19). A total of 19 samples including two duplicate samples were collected and analyzed by EDXRF for metals. The analytical results presented in Table 5 indicated that lead was reported at concentrations ranging from 230 mg/kg to 1,300 mg/kg, where 15 of 19 samples analyzed exceeded the R-SRL of 400 mg/kg and/or minimum GPL of 290 mg/kg. In addition, arsenic detection limits were all elevated due to interference of lead, and were deemed invalid. No other detected metals were reported above the R-SRLs and/or minimum GPLs.

### **6.6.6.2 Stream Sediment Following July 2006 Flooding**

Surface stream sediments were sampled in September 2006 following flooding in July 2006. Surface stream sediment samples were collected in Aravaipa Creek at three cross-sections (Figure 19). A total of 24 samples, including one duplicate sample, were collected and analyzed by EDXRF for metals. The analytical results presented in Table 11 indicated that lead was reported at concentrations ranging from <10 mg/kg to 740 mg/kg. One sample exceeded the R-SRL of 400 mg/kg and the minimum GPL of 290 mg/kg. Arsenic was also detected at one location above the R-SRL. However, due to the potential of lead interfering with the arsenic results, this detection is considered invalid. No other detected metals were reported above the R-SRLs and/or minimum GPLs.

Surface stream sediment samples were collected in Laurel Creek at two cross-sections (Figure 19). A total of 11 samples, including one duplicate sample, were collected and analyzed by EDXRF for



metals. The analytical results presented in Table 6 indicated that lead was reported at concentrations ranging from 160 mg/kg to 2,100 mg/kg, where five of 11 samples analyzed exceeded the R-SRL of 400 mg/kg and the minimum GPL of 290 mg/kg. Arsenic was also detected at seven locations above the R-SRL. However, due to the potential of lead interfering with the arsenic results (Section 5.1), these detections are considered invalid. No other detected metals were reported above the R-SRLs and/or minimum GPLs.

### **6.6.6.3 Fixed-Base Laboratory Analysis of Stream Sediment**

Of the stream sediment samples that were collected prior to the July 2006 flood event, four were retained for laboratory analyses for metals and cyanide. The analytical results presented in Table 8 indicated exceedances of both the R-SRL and/or minimum GPL of lead in three of the four samples analyzed with the highest concentration at 590 mg/kg. Arsenic was also reported at concentrations exceeding the R-SRL in three of the four samples analyzed. Analytical results of five sediment samples collected after the July 2006 flood event (Table 8) also reported lead and arsenic at concentrations above their R-SRLs and/or minimum GPLs in all five samples. In addition, in all cases where arsenic exceeded the R-SRL, the corresponding lead concentration also exceeded the R-SRL and/or minimum GPL.

## **6.7 GROUNDWATER CHARACTERIZATION**

### **6.7.1 Monitor Well Installations**

In November 2005, URS directed the drilling and installation of four groundwater monitor wells at locations within the WQARF site. Details of the well installation construction are contained in the *Final Groundwater Monitoring Wells Installation* report prepared for ADEQ (URS, 2006a).

URS contracted with Prosonic of Chandler, Arizona to drill four soil borings. Prosonic is an Arizona-licensed driller (Arizona Department of Water Resources (ADWR) License No. 79). The location of the monitor wells is shown on Figure 6. Prosonic advanced the soil borings using a rotosonic drill rig equipped with 7-inch diameter drive casing and an inner 6-inch diameter core barrel to drill a continuous core. This method used high frequency vibrations to advance the drive casing during drilling and to maintain borehole stability. Once a 10-foot section was cored, the core barrel was tripped out and the unconsolidated core extruded from the core barrel and placed in five-foot section plastic containers. The four (4) borings were advanced to total depths of between 82 and 84 feet bgs.

Monitor wells KW-1, KW-2, KW-3, and KW-4 were constructed in accordance with ADWR regulations. After the borings were advanced to a total depth of between 82 and 84 feet bgs, the inner



core barrel casing was tripped out. All well casing, filter pack and annular seal materials were placed through the outer drive casing as the pipe was withdrawn. Well casing consisted of 4-inch diameter Schedule 40 flush-threaded blank PVC from the surface to near 30 feet bgs and 4-inch diameter Schedule 40 flush-threaded 0.020-inch PVC slotted well screen from near 30 feet bgs to near 80 feet bgs, and included a threaded PVC bottom end cap. A filter pack of 8-12 mesh Colorado Silica Sand was placed from approximately 28 feet bgs to bottom. A bentonite pellet seal approximately 5-6 feet thick was placed above the filter pack. A bentonite slurry seal approximately 23 feet thick was placed above the bentonite pellets and allowed to set for 2 hours. Type I cement grout with 3-5 percent bentonite was installed from the top of the bentonite slurry seal to the surface. The well was completed with a traffic-rated, flush-grade steel vault. Completion and construction summaries are presented in the well installation report (URS, 2006a).

Prosonic developed the groundwater monitoring wells by surging and swabbing using a 5-gallon stainless steel bailer. The wells were then pumped at approximately 2.0 to 3.5 gpm using a 2-inch diameter portable submersible pump installed on 2-inch diameter galvanized steel drop pipe. The wells were pumped until at least three well volumes of water were removed. Field water parameters (pH, temperature, and conductivity) were recorded for each purged well volume to confirm that groundwater quality had stabilized to within 10 percent of the value recorded for the previous sample. Approximately 330 to 385 gallons of water was purged from each monitor well. The development water was discharged to the ground at least 25 feet down gradient from each well.

A URS Arizona-registered land surveyor surveyed the elevation of the monitor wells. The top north of the 4-inch PVC casing and the top north edge of the rim of the vault lid was surveyed.

## **6.7.2 Sampling Methodology**

URS collected groundwater samples from the four monitor wells on a quarterly schedule beginning in December 2005. Sampling was conducted on the following dates:

- December 5 and 6, 2005
- January 19, 2006
- March 16, 2006
- May 25 and 31, 2006
- October 5, 2006
- January 17, 2007
- May 9, 2007



- August 10, 2007
- October 5, 2007
- April 17, 2012
- February 21, 2013

During each event, water level elevation was measured in each well prior to sampling. Using a decontaminated portable submersible pump and clean tubing, wells were purged prior to sample collection. During purging, groundwater was monitored with a field parameter meter for temperature, conductivity and pH. Samples were collected from a decontaminated sampling port and submitted to an Arizona-licensed analytical laboratory for analysis of 5 major cations, 3 major anions, and 14 total and dissolved metals. Samples to be analyzed for dissolved metals were field-filtered. Samples also were analyzed for some or all of the following general chemistry parameters: alkalinity, nitrate, nitrite, cyanide, total dissolved solids, total suspended solids, pH, specific conductivity and temperature.

Additionally, the following domestic wells near the Site were sampled on the dates shown:

- January 19, 2006 - Well No. 3, an old irrigation well with open steel casing located on parcel 110-47-003g in Aravaipa Creek channel southwest of the Upper Tailings Pile
- May 2, 2006 – domestic wells on parcels 110-47-001m and 110-47-001i
- May 25, 2006 - domestic wells on parcels 110-47-001m and 110-47-001i
- November 20, 2006 – domestic well on parcel 110-47-003b
- August 29, 2007 – domestic well on parcel 110-47-001m
- October 17, 2007 - domestic well on parcel 110-47-001m

Water level elevations were not measured in these wells. Because the domestic wells are in constant use, they were purged for 1 to 2 minutes prior to sampling. Water samples collected from domestic wells were submitted to an Arizona-licensed analytical laboratory and analyzed for total and dissolved metals. Selected samples also were analyzed for some or all of the general chemistry parameters analyzed at the Site monitor wells. The domestic wells are illustrated on Figure 3.

### **6.7.3 Chain of Custody Procedures**

Chain of custody procedures are described in Section 4.5.4.



#### **6.7.4 Equipment Decontamination**

Non-disposable sampling equipment was decontaminated between each sample. The decontamination process consisted of washing equipment with a laboratory grade detergent (Alconox) and de-ionized water, and double rinsing the equipment with de-ionized water.

#### **6.7.5 Field Documentation**

Field documentation procedures are described in Section 4.5.5.

#### **6.7.6 Investigation-Derived Waste**

The purge water generated during the sampling of the wells was discharged at least 25 feet down gradient from each well.

#### **6.7.7 Data Management**

Groundwater elevations and water quality data were formatted and submitted to ADEQ for inclusion in the ADEQ Groundwater Quality Database. Data submittals were made using guidance documents prepared by ADEQ.

#### **6.7.8 Results of Groundwater Sampling**

Groundwater laboratory analytical reports are provided in Appendix G. A URS chemist performed a QA/QC verification of the analytical data to verify completeness, precision, and accuracy. Data verification memoranda are presented in Appendix E.

##### **6.7.8.1 Onsite Monitoring Wells**

Monitor well KW-1 is located up gradient of the tailings piles at the southeast edge of source area parcel 110-47-003gs. Monitor wells KW-2 and KW-4 are located on the Site in the processing area between the two tailings piles. Monitor well KW-3 is located down gradient from the two tailings piles at the northwest edge source area parcel 110-47-003g. The four wells have been sampled 11 times since installation in November 2005, with the latest sampling round on February 21, 2013.

No metals have been reported in those wells at concentrations exceeding the corresponding AWQS during any of the sampling rounds. Tables 13 through 16 include historical groundwater quality data from the four onsite monitor wells.

Groundwater elevation data were collected to assess changes in groundwater elevation and assist in identifying the causes of any elevation changes, such as seasonal variations or offsite activities that



may impact groundwater levels (Table 17). Figure 20 presents groundwater elevation contours for the Site using data collected on February 21, 2013.

A total of 49 samples, including 7 duplicate samples, were analyzed for the following general chemistry parameters: four major cations, three major anions, alkalinity, nitrate, nitrite, and cyanide. None of the parameters were detected at concentrations indicative of contamination or poor water quality:

- Alkalinity ranged from 130 to 200 mg/L in all samples tested
- Calcium ranged from 39 to 49 mg/L in all samples tested
- Magnesium ranged from 7.5 to 20 mg/L in all samples tested
- Potassium ranged from 2.0 to 7.3 mg/L in 23 of the 36 samples tested
- Sodium ranged from 19 to 53 mg/L in all samples tested
- Chloride ranged from 5.2 to 7.2 mg/L in all samples tested
- Fluoride ranged from 0.50 to 0.76 mg/L in 32 of the 37 samples tested
- Sulfate ranged from 14 to 32 mg/L in all samples tested
- Cyanide was not reported at concentrations exceeding the laboratory reporting limit in the samples analyzed

Nitrate ranged from 0.79 to 4.6 mg/L in all samples tested, while nitrite was reported only in the first two samples collected from KW-2, and ranged from 0.022 to 0.042 mg/L.

#### **6.7.8.2 Offsite Domestic Wells**

Four domestic water wells located outside the source area parcels were sampled for 15 total metals to assess water quality offsite and to assist in characterizing groundwater quality in the area (Figure 3). Groundwater samples for metals were unfiltered for total metals. Analytical results from domestic well samples are summarized in Table 18. Laboratory reports are provided in Appendix G.

Arsenic was detected in three samples; 0.0043 mg/L in 110-47-001i, 0.0062 mg/L in sample 110-47-001m dated 5/2/2006, and 0.0031 mg/L in sample 110-47-001m dated 5/25/2006. The AWQS level of 0.01 mg/L for arsenic was not exceeded.

Detectable concentrations of copper were identified in samples from the 110-47-001i and 110-47-001m wells, ranging from 0.0027 mg/L to 0.17 mg/L. There is no AWQS level established for copper.



Detectable concentrations of total iron were identified in samples from the 110-47-001i, 110-47-001m, and 110-47-003b wells, ranging from 0.18 mg/L to 9.7 mg/L. There is no AWQS level established for iron.

Lead was detected in the sample collected from the 110-47-001m well on August 29, 2007 and exceeded the AWQS for lead of 0.05 mg/L, resulting with a re-sampling event on October 17, 2007. The additional analytical results for this well did not detect lead above the laboratory detection limit, therefore the detection of lead above the AWQS is not confirmed. Lead also was detected in the 110-47-001i well at 0.0049 mg/L, which is less than the AWQS.

Detectable concentrations of manganese were reported in samples from the 110-47-001i and 110-47-001m wells ranging from 0.0056 mg/L to 0.0758 mg/L. There is no AWQS level established for manganese.

Detectable concentrations of zinc were reported in samples from the 110-47-001i and 110-47-001m wells ranging from 0.0597 mg/L to 4.34 mg/L. There is no AWQS level established for zinc.

Concentrations of calcium ranged from 29 mg/L to 41 mg/L. Concentrations of magnesium ranged from 5.2 mg/L to 8.0 mg/L. Concentrations of potassium ranged from below detection to 2.5 mg/L. Concentrations of sodium ranged from 18 mg/L to 20 mg/L.

In July 2001, ADEQ conducted a regional groundwater sampling event of sixteen domestic water wells located in the vicinity of the Site were sampled for 19 total metals to assess water quality offsite and to assist in characterizing groundwater quality in the area.

Arsenic was detected in all sixteen samples; ranging from 0.0016 mg/L at the 110-47-001i well to 0.0047 mg/L at NC-OK. The AWQS level of 0.01 mg/L for arsenic was not exceeded.

Detectable concentrations of copper were identified in the 110-47-006 well at 0.0071 mg/L. There is no AWQS level established for copper.

Detectable concentrations of total iron were identified at ten wells, ranging from 0.042 mg/L to 2.8 mg/L. There is no AWQS level established for iron.

Lead was detected in the sample collected from the Garwood well at 0.0022 mg/L, which is less than the AWQS of 0.05 mg/L.

Detectable concentrations of manganese were reported in samples from the Luepke #1 & #2 and Stampfer wells at 0.021 mg/L, .023 mg/L, and 0.046 mg/L, respectively. There is no AWQS level established for manganese.



Detectable concentrations of zinc were reported in four wells ranging from 0.051 mg/L to 0.14 mg/L, respectively. There is no AWQS level established for zinc.

Concentrations of calcium ranged from 25 mg/L to 74 mg/L. Concentrations of magnesium ranged from 3.2 mg/L to 12.0 mg/L. Concentrations of potassium ranged from below detection to 2.2 mg/L. Concentrations of sodium ranged from 11 mg/L to 56 mg/L.

## **6.8 METEOROLOGICAL – AIR MONITORING**

### **6.8.1 Site Historical Air Monitoring**

The remote location of the Site results in a lack of historical local meteorological data. From 1953 through 1978 a cooperative meteorological station located 3 miles south of the Town of Klondyke reported maximum and minimum temperatures, precipitation, and snowfall. No records of wind speed and direction are listed in the data set for that station. During this period, precipitation at Klondyke averaged 15.1 inches annually with an average of 1.5 inches of snowfall (WRCC, 2007). Precipitation may be up to 25 inches per year in the higher mountain areas (SCS, 1998).

The Bonita and Fort Grant stations, located approximately 35 miles southeast of Klondyke, recorded wind and temperature records, respectively. Prevailing winds from the period of 1987 to 2003 were from the north by northwest along the length of the valley with an average speed of 1.4 miles per hour (mph). (AZMET, 2007) The Fort Grant station has been operated discontinuously from 1900 to the present. Historically, daily temperatures range from 32 °F to 92 °F with a record high of 111 °F and record low of 2 °F (WRCC, 2007).

URS obtained general wind information from interviews with residents in the vicinity of the Site (Schnell, 2007). The prevailing wind direction is generally downslope to the east and southeast in the morning, reversing mid-day to an upslope flow to the west and northwest. Winds are generally stronger in the afternoon, ranging from 5 to 10 mph. Storm events typically alter the wind direction and may increase velocity to 10 to 20 mph or more. During winter storms the wind is usually to the east, while during summer monsoon storms the wind is typically to the west.

### **6.8.2 Site Air Monitoring**

Prior to construction activities for the Klondyke ERA at the Upper Tailings Pile, two meteorological stations were installed on properties adjacent to the Site: an east station on the Schnell property, and a west station on the Stoddard property. Both stations operated for the duration of construction activities to monitor wind speed and direction, temperature and barometric pressure. The distribution of winds reported by the east station during the monitoring period (February 18 – June 12, 2008)



shows that winds come from the northwest or the southeast and are generally less than 10 mph. Refer to the Ambient Air Monitoring Report for locations (VSI Environmental, 2008).

## **6.9 ARCHAEOLOGICAL AND CULTURAL RESOURCES SURVEY**

URS conducted a cultural resources survey at the Site and vicinity in June 2004 and reported the findings in the *Final Cultural Resource Survey Report* (URS, 2004b). The cultural resources studies was designed to identify and evaluate the historical significance of the extant buildings and archaeological remnants of the mill site, other cultural resources in the vicinity, and assess impacts of ground disturbing activities related to the RI study. Historical research was conducted through literature reviews, and background information was gathered through record research of prior studies of the Klondyke area.

Historical research and oral interviews were conducted to obtain information regarding the history of the project vicinity, the community of Klondyke, mining in Arizona and the Aravaipa District, flotation mills, the history of mill operations and the community of workers. Primary sources of information included the ASU Hayden Library in Tempe and the Phoenix Public Library. The reference librarian at the Fort Smith Public Library in Fort Smith, Arkansas also provided articles describing the history of the Athletic Mining and Smelting Company.

Research completed in June 2004 included a study of the ownership history of the Athletic Mining Company Mill site and other primary records at the Graham County Recorder's office in Safford, Arizona (Figure 21). Articles and books about the history of Klondyke, mining, and the Athletic Mining Company were reviewed at the Graham County Historical Museum in Thatcher. A taped oral interview with Clay Turnbull, a former Athletic Mining Company employee, and his wife Alice, provided information about the operation of the mill (Turnbull and Turnbull, 1990). An oral interview with Milton Rhea, a former Athletic Company employee, was conducted at the mill site in June 2004 (Rhea, 2004). Inventory and architectural field forms are located within the Final Cultural Resource Survey Report (URS, 2004a).

A total of 80 acres were intensively surveyed by walking the study area at intervals of 20 meters or less. Features were inventoried, mapped, and photographed. Table 1 includes a description of the features identified during the survey. Archaeological sites defined using the Arizona State Museum (2004) definition and cultural resources were evaluated using National Register of Historical Places criteria.

The project area was located on private land, which includes 25 acres where the mill site is located and the immediate surrounding area. The defined survey encompasses the East 1/2 of the Southwest



1/4 of Section 6, Township 7 South, Range 20 East of the Gila and Salt River Baseline and Meridian.

The site can be divided into three areas: the mill processing area, residential area, and community area, where a church is located. A total of 35 features were defined which include 12 buildings, 7 structures, 4 concrete foundations, 3 objects (tanks), 3 earthworks, 2 piles of building demolition debris, 2 trash concentrations, and 2 tailings piles (URS, 2004b) (Figure 21).

### **6.9.1 Mill Processing Area**

Nineteen features were defined in the processing area. The two large tailings piles, standing approximately 20 feet high, are the most prominent features of the site. Most of the other features are remnants of the mill processing facilities that were located between the two tailings piles, but some postdate the 1957 closure of the mill.

Features identified within the Mill Processing Area are a partial ore crushing and conveyor system, a small two-story building apparently related to the system for handling the crushed ore (mill feeder system), the concrete slab foundation of the mill building, a crushed concentrator tank, fuel tanks, an electrical transformer structure, a loading dock, a mechanic's shop, a wooden storage shed, part of the collapsed tailings piping system, a pile of demolition debris (mostly lumber), a small livestock pen, a modern equipment/hay shed, and a probably modern concrete slab foundation.

### **6.9.2 Residential Area**

Features identified within the Residential Area are a dirt road that mill workers referred to as Main Street, which divided the residential area into eastern and western parts. The 14 features identified within the residential area include five worker residences, a cluster of building debris that may represent three more collapsed houses, an assay office/communal laundry and shower building, a concrete foundation, a collapsed water tower and tank, a standing metal tank, two trash concentrations, and two earthworks (URS, 2004b).

Two earthen berms were identified on the eastern and western sides of the residential area. These berms, which are approximately 10 feet wide and 4 feet high, reportedly were bulldozed to divert rainfall runoff around the site (Rhea, 2004).

### **6.9.3 Community Area**

Two features were designated at the northern end of the camp - a church and an outhouse. The church building was built in 1955-1956, shortly before the mill ceased operations. The Athletic Mining Company donated land for the church, which was built by and for Athletic Mining Company



employees and other local residents as well. The church currently is under different ownership than the rest of the camp, reflecting the original donation of land for the church. The building has not served as a church for some time, and currently is used as a taxidermy shop.

A wooden outhouse is located approximately 120 feet west of the church. The characteristics of the outhouse indicate it is not of historical age, and a recent magazine and fresh toilet paper found inside reflect ongoing use of the facility.

## **6.10 BIOLOGICAL SURVEY**

A biological survey was conducted by URS in June 2004 at the Site. The findings were reported in the *Final Biological Survey Report* (URS, 2004a). The area surveyed for this report consisted of lower Laurel Creek adjacent to and upstream of the Site; and Aravaipa Creek adjacent to, upstream, and downstream of the Site. On-the-ground surveys were conducted within the 10-acre site.

The study began with the collection of background information on localities and status for vertebrate groups and plant communities through the review of aerial maps, topographic maps, general biological information obtained from the initial reconnaissance survey, and information gathered from the local community. Field surveys were conducted from June 7 through June 10, 2004 by URS biologists. Survey data were recorded and photographs were taken and logged. The four-day survey was conducted on the 10-acre Site with an approximately 3-mile radius buffer. Survey methods were specific to each individual group during this study.

Vegetation was surveyed by categories; over story, cover, basal, shrub-like, and ground level. Amphibians were identified in or around the stock tank, the only surface water source on site, by listening for calls at night, and locating the call by triangulation until a point of reference was identified. Reptiles were surveyed by walking the habitat and searching under rocks or other places where reptiles would go to escape the sun. Birds were identified by habitat types, calls or songs, and visual identification throughout the day. Mammals were identified through habitats, such as vegetation types, burrows, or scat. Small mammals were trapped with Sherman live traps placed in 32 trap stations.

During the biological survey approximately 53 species of plants were observed representing two biomes and three biological communities within them, four species of reptiles, 32 species of birds, and 12 species of mammals. The site appears to provide year round habitat for resident birds, mammals, and reptiles. However, due to the lack of water in Aravaipa Creek, no aquatic species are present. The terrestrial species that occupy the Klondyke Site appear to be healthy and thriving.



### 6.10.1 Vegetation

Vegetation was characterized in the following order: dominant tree-level species, shrub level species, and ground level species. The Site was divided into quads: northeast, northwest, southeast, southwest; and the Aravaipa Creek floodplain.

The vegetation survey discovered that the area was once heavily grazed by livestock. Biologists noted two horses currently grazing in the area. There was also a high density of broom snakeweed (*Gutierrezia sarothrae*) and burroweed (*Isocoma tenuisecta*), which livestock do not eat.

The northeastern part of the project area consists of a semi-desert scrubland dominated by shrubby velvet mesquite (*Prosopis velutina*) and catclaw (*Acacia greggii*). Dominant shrubs include broom snakeweed (*Gutierrezia sarothrae*) and burroweed (*Isocoma tenuisecta*). Ground cover includes the perennial slimleaf bursage (*Ambrosia confertiflora*) and the annuals eriastrum (*Eriastrum* sp.), fiddleneck (*Amsinkia* sp.), and plantain (*Plantago* sp.).

Vegetation identified in the west and southwest sections of the study area consists of a riparian scrubland community. Part of the area consists of many shrubby sprouting mesquite stumps as large as 20 inches in diameter at ground level. The riparian strand in the deep undeveloped sandy soils along the margin of the Aravaipa Creek streambed consists primarily of burrobrush (*Hymenoclea monogyra*). A complete list of vegetation identified at the site is provided in the report (URS, 2004a).

### 6.10.2 Amphibians

No amphibians were observed during the survey due to the lack of water in Aravaipa Creek, Laurel Creek, and the Klondyke area. However, one evening a single toad call was heard from the direction of the southern bank of Aravaipa Creek. The species was not located or identified.

The Lowland Leopard Frog has Endangered Species Act (ESA), BLM, or Arizona Game and Fish Department (AGFD) special status and was not found at the Site during this study.

### 6.10.3 Reptiles

Two species of rattlesnake are known to be at the Site: the Western diamondback (*Crotalus atrox*) and the Mohave rattlesnake (*Crotalus scutulatus*). However, rattlesnakes were not observed during the survey.

Four species of lizards were identified at the Site, with the greater earless lizard (*Cophosaurus texanus*) being the most common at the Site. The Western whiptail (*Cnemidophorus tigris*), Eastern



fence lizard (*Sceloporus undulates*), and the desert spiny lizard (*Sceloporus magister*) were commonly surveyed at the Site.

The only aquatic reptile in the vicinity of Aravaipa Creek is the Sonoran mud turtle (*Kinosternon sonoriens*). The Sonoran desert tortoise (*Gopherus agassizii*) and the giant spotted whiptail (*Aspidoscelis burti stictogrammus*) have ESA, BLM or AGFD special status.

#### 6.10.4 Birds

The types of birds surveyed at the site are dependent on the plant communities, availability of water, and season. During the biological survey 32 species of birds were surveyed, with the Ash-throated Flycatcher (*Myiarchus cinerascens*), Bell's Vireo (*Vireo bellii*), and the Black-tailed Gnatcatcher (*Poliophtila melanura*) being commonly observed. A complete list of birds observed is provided in the report (URS, 2007c).

Birds that have ESA, BLM, or AGFD special status include: northern gray hawk (*Asturina nitida maxima*), common black-hawk (*Buteogallus anthracinus*), western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), southwestern willow flycatcher (*Empidonax traillii extimus*), American peregrine falcon (*Falco peregrinus anatum*), thick-billed kingbird (*Tyrannus crassirostris*), and tropical kingbird (*Tyrannus melancholicus*).

#### 6.10.5 Mammals

Nine species of medium to large mammals were observed at the site. The species ranged from Cottontail Rabbits (*Sylvilagus auduboni*) to Mule Deer (*Odocoileus hemionus*). Four trap lines were laid to trap small nocturnal rodents. A total of 184 traps set over three nights yielded 147 small rodent individuals of seven species. The majority of small mammals trapped were the Merriam's kangaroo rat (*Dipodomys merriami*), followed by the cactus deer mouse (*Peromyscus eremicus*), and the Bailey's pocket mouse (*Chaetodipus baileyi*). A complete list of mammals identified is listed in the report (URS, 2007c).

#### 6.10.6 Aquatic Invertebrates

A literature review of the aquatic invertebrates revealed 50 families containing 133 taxa of invertebrates (including 1,069 insects) found in the Aravaipa Creek Drainage (Minckley, 1981). Benthic invertebrates are most abundant and biomass is highest during winter and spring. There is a consistent decline during summer rains and subsequent flooding. The Maricopa Tiger Beetle has ESA, BLM, or AGFD special status.



### **6.10.7 Fish**

A literature review of the fish populations in the Aravaipa Creek Drainage revealed eight native fish species, three of which are endangered. They consist of one herbivore – the Desert Sucker (*Catostomus clarki*); three omnivores – the Longfin Dace (*Agosia chrysogaster*), Speckled Dace (*Rhinichthys osculus*), and the Sonora Sucker (*Catostomus insignis*); and three carnivores – Spikedace (*Meda fulgida*), Loach Minnow (*Tiaroga cobitis*), Roundtail Chub (*Gila robusta*), and the Gila Topminnow (*Poeciliopsis occidentalis occidentalis*) (Minckley, 1981).

Under the ESA, the Gila Topminnow, the Loach Minnow, and the Spikedace are listed as endangered and the Desert Sucker, Longfin Dace, Sonora Sucker, Speckled Dace, and the Roundtail Chub are considered Species of Concern, meaning that their conservation status may be of concern. Aravaipa Creek is designated as critical habitat for the Spikedace and Loach Minnow (AGFD, 2013).

## **6.11 PERMITS AND AUTHORIZATION**

The USFWS provided URS with a list of species that may occur within the project area that are listed as threatened, endangered, or are proposed to be listed as such under the ESA. Threatened and endangered species are protected by federal law and must be considered prior to project development. After review of the list, it was concluded that it was unlikely that listed species would be encountered during characterization activities and a biological assessment was not conducted. Listed species were not encountered during the tailings characterization activities.



## 7.0 CONTAMINANT FATE AND TRANSPORT

### 7.1 POTENTIAL ROUTES OF MIGRATION

The results of investigations at the Site identified antimony, arsenic, cadmium, copper, lead, manganese, mercury, vanadium, and zinc as contaminants of concern. Analyses of soil and tailings samples at the Site identified the activities at the historic mill site and Upper and Lower Tailings Piles as primary contaminant sources. However, as will be presented and discussed in Section 6.5, a secondary source of metals contamination was identified during the site characterization activities – mine tailings and waste rock located in Laurel Creek upstream from the Site near the abandoned Grand Reef Mine. Historical milling of the Dog Water mine tailings on parcel 110-47-006 resulted in elevated metals concentrations on that parcel as well.

A review of historical investigations identified the affected media as soil and stream sediments. Although one of the previous investigations detected elevated concentrations of metals in groundwater down gradient from the Site, there is no information that groundwater beneath the Site has been impacted by the tailings piles. For this reason, groundwater will not be considered in detail as a contaminant source, migration pathway or affected media.

#### 7.1.1 Migration Pathways

There are two categories of pathways for migration of contaminants at the Klondyke Site: physical migration and chemical migration. The physical migration pathways and transport mechanisms for metal contaminants in the tailings are primarily surficial erosion by storm water runoff, local erosion by flooding, wind erosion, and vertical migration to groundwater. Chemical migration pathways include dissolution, mobilization and dispersion of mineral species by infiltration of slightly acidic rain water as well as ARD generated in the tailings piles.

The physical migration pathway and associated transport mechanisms that affect the tailings piles become significantly more important as the stream channel geomorphology changes with lateral erosion of the channel during stream flow and flooding events. Recent geomorphologic studies of historical lateral erosion evaluated the possible impact of local erosion and flooding on contaminant migration (Fuller 2002; 2006).

##### 7.1.1.1 Historical Lateral Erosion

Lateral erosion and changes in channel position were documented using seven historical aerial photographs taken from 1937 to 2002 and four topographic maps published from 1938 to 2002 (Fuller, 2002). The 2002 topographic map was constructed using an aerial photographic survey conducted as part of the RI. These historical records indicate that up to 860 feet of lateral bank



erosion has occurred on Aravaipa Creek near the Site since 1937, with a mean annual erosion rate of about 13 feet per year. From 1938 to 1972, the Aravaipa Creek channel at the Site degraded by up to 10 feet, and subsequently aggraded up to eight feet after 1972.

Field observations indicate that active lateral erosion should be expected in the near future along the primary channel banks of Aravaipa Creek closest to the Site. Actively eroding vertical cut banks were observed less than 30 feet from the edge of the tailings. The channel banks are not stabilized by vegetation and consist of highly erodible unconsolidated silty fine sand and gravel. The tailings piles have not been impacted by erosion and lateral movement along Laurel Creek during the period that historical records are available (Fuller, 2002).

Given the field conditions and analysis of evidence from the historical record, erosion of the tailings into Aravaipa Creek could occur during a single moderate-sized flood event. Erosion of the tailings could occur within three years. If a “no action” remedial action alternative is employed, it is highly likely that the tailings will be eroded and dispersed into Aravaipa Creek in the near future (Fuller, 2002).

During July 2006 a moderate storm event on Aravaipa Creek resulted in flooding along Aravaipa Creek and Laurel Creek that impacted the Site. Subsequently a second aerial photographic survey was conducted at the Site and a 2006 topographic map was prepared. According to Fuller (2006), Aravaipa Creek showed bank widening on the northeast bank (the same side as the Site) as a result of the 2006 flooding event. The water did not cause scouring and there was no evidence of significant erosion of the tailings piles. The flood waters of Laurel Creek met the tailings piles at Klondyke Road and at several places on the western side of the Site. The flood waters occurred on the Site as sheet flow and did not significantly erode the tailings piles.

### ***7.1.1.2 Physical Modes of Contaminant Migration***

#### ***7.1.1.2.1 Surface Water Migration***

In June 2008, ADEQ and URS completed the consolidation, capping with a two-foot clean soil cover and installation of gabion mattresses for erosion protection on the Upper Tailings Pile. The Upper Tailings Pile is no longer considered a source for surface water migration.

Site reconnaissance visits by URS and a geomorphology study by Fuller have observed evidence of erosion at the Upper and Lower Tailings Piles. Runoff from rainfall events has eroded the tailings piles and formed small rills or channels that collect and direct runoff and minor amounts of sediment into Aravaipa Creek (Fuller, 2002). Small channels on the north and south portions of the Upper Tailings Pile direct runoff and sediment to Aravaipa Creek. A small channel at the north end of the



lower tailings pile directs runoff into a small wash that trends southwest and drains into Aravaipa Creek. Contaminants can be mobilized by surface water erosion and migrate into Aravaipa Creek. These channel features that drain runoff from the tailings piles to Aravaipa Creek were bermed in May 2006 to mitigate runoff as part of an interim ERA. The berms were examined following the July 2006 storm event and were found intact, having successfully served to mitigate runoff. Pondered water was observed on the tailings piles behind some of the berms. However, the Upper Tailings Pile has since been capped and further, therefore erosion of the Upper Tailings Pile has ceased.

Contaminant migration by surface water will be limited to intermittent stream flow during rainfall and flood events. During significant rainfall events, runoff from the exterior slopes of the tailings piles will transport dissolved contaminants and unknown amounts of suspended sediment containing contaminants to Aravaipa Creek. Previous investigations conducted while Aravaipa Creek was flowing did not show that surface water was impacted by runoff from the tailings piles (ADEQ, 1993). However, there is the potential during extreme flood conditions for Aravaipa Creek to erode the tailings piles and transport significant amounts of suspended and dissolved contaminants downstream (Fuller, 2002).

Following flooding of Aravaipa Creek in July 2006, Fuller revisited the area to evaluate the impact of the 2006 flood event on the floodplain and stream channel and to evaluate the viability of the proposed ERA for the tailings sites and existing channel conditions. High water marks showed that Aravaipa Creek overtopped its banks with shallow non-erosive sheet flows. High water marks along the upstream side of the tailings slope were observed and caused a slight scour line. Floodwaters did not reach the tailings pile on the downstream side. Laurel Creek overtopped its banks in several locations on both sides of the wash and had an approximate depth of less than two feet (Fuller, 2006).

#### *7.1.1.2.2 Airborne Migration*

In June 2008, ADEQ and URS completed the consolidation, capping with a two-foot clean soil cover and installation of gabion mattresses for erosion protection on the Upper Tailings Pile. The Upper Tailings Pile is no longer considered a source for airborne migration.

The southern and extreme eastern portions of the Lower Tailings Pile show evidence of a deflation surface. Wind erosion has removed fine sands and silts from the tailings pile and deposited the material downslope on the south side of the Lower Tailings Pile within approximately 100 ft of Aravaipa Creek. In addition, the northern portion of the Lower Tailings Pile consists of soft, loose fine sand and silt material that has been transported by the wind and deposited downslope on the east side of the Lower Tailings Pile. Data collected during the consolidation and capping of the upstream pile indicated the prevailing wind direction is from the northwest and the southeast, Occasional



strong winds will continue to serve as a pathway for contaminant migration. Approximately 50 percent of the surface of the Lower Tailings Pile is protected from wind erosion by a thin crust (approximately ¼-inch thick). Airborne migration of contaminants also may be caused by Site activities that generate dust, such as clearing and grubbing during harvest of mesquite trees for firewood, or riding on the tailings piles with all-terrain vehicles (ATVs) or motorcycles. Although such activities may not generate large quantities of airborne dust, the proximity of human receptors to the dust will likely increase exposure to contaminants.

#### *7.1.1.2.3 Groundwater Migration*

Contaminant migration in groundwater is a function of the depth to groundwater, which is affected by the amount of rainfall and flow in Aravaipa Creek, and a function of the vertical migration pathway from the tailings pile to the aquifer. Subsurface soil characteristics at the Site have been described in soil borings advanced during the installation of four monitor wells. Soil ranges from coarse-grained gravelly sand and silty sand to fine-grained silty clay and clay. A 20 to 24 foot thick clay layer occurs between 36 and 75 feet bgs, depending on the well. This clay layer appears to be an effective barrier to vertical migration of groundwater, which is present in fine-grained well-graded sand below 67 to 75 feet. The aquifer is confined by the clay layer, as shown by the first occurrence of groundwater below the clay-sand interface. The water level rises to 40 to 45 feet in the completed wells (30 feet above the top of the aquifer), which is indicative of a confined aquifer.

Shallow groundwater conditions in the channel of Aravaipa Creek were evaluated during a flood event in 1993 (ADEQ, 1993). Laboratory analyses of three shallow groundwater samples indicated that the sample collected upstream from the Upper Tailings Pile did not contain detectable metals, and probably was not impacted by surface water runoff from the tailings piles. However, the two downstream samples did contain metals, which suggests that runoff from the tailings piles has impacted shallow groundwater at and immediately downstream from the Site. This result indicates that shallow groundwater is a potential pathway for contaminant migration during flood events.

Confined aquifer conditions were evaluated by collecting quarterly groundwater samples at depths of approximately 75 feet bgs from the four monitor wells. No metals were detected at concentrations exceeding the corresponding AWQS, where established. Since dissolved metals have a strong tendency to adsorb onto clay minerals and iron hydroxides, it is unlikely that a significant amount of metals contamination will be transported through the clay aquitard to the deeper aquifer, unless a conduit is present. These results suggest that, under normal conditions, deeper groundwater is not currently a significant pathway for contaminant migration and exposure.



### 7.1.1.3 *Chemical Modes of Contaminant Migration*

#### 7.1.1.3.1 *Chemical Mobilization of Contaminants*

Two studies of tailings materials were conducted to assess the potential for chemical mobilization of metal contaminants at the Site. The first study identified the lead- and arsenic-bearing minerals present in tailing piles and evaluated the bioavailability of lead and arsenic. The second study tested tailings materials for acid generation potential and the metal leaching capacity of the tailings, which are used to evaluate the potential mobility of metals in the tailings.

#### **Geochemistry of the Tailings**

A geochemistry study was conducted on the two tailings piles at the Site to evaluate the presence of ARD, metal concentrations, and metal leaching capacity of the tailings. Results of ARD and metal leaching capacity are used to evaluate the mobility of metals in the tailings. The geochemistry study included static testing, kinetic testing and metals analysis of the solutions resulting from those tests.

Mobility of several metals is typically enhanced under acidic conditions. In some cases near neutral to alkaline drainage may also contain metal contaminants, particularly if alkaline-soluble metals such as arsenic and molybdenum are present in the tailings minerals. Therefore, the objectives of the geochemistry study were to evaluate potential metal leaching and net acid generation. The results were used to provide:

- Age of ARD and metal leaching
- Rates of ARD and metal leaching
- Spatial variability of ARD and metal leaching (areal extent and vertical profiles)
- Total concentrations of metals in the tailings
- Drainage chemistry.

A 3-stage approach involving Static Tests Part I, Static Tests Part II, and Kinetic Tests was implemented.

Static Tests Part I included analysis of paste conductivity, paste redox, paste pH and ABA.

Static Tests Part II included elemental analysis by ICP scan and mineralogy analysis by electron microprobe scanning. Ten percent of the samples of the Static Tests Part I (eight samples) were submitted for Part II static tests. Of the eight samples, two were potentially non acid-generating, two had uncertain acid-generating potential and four were potentially acid-generating samples (URS, 2003a).



Although static tests provide a way of determining acid generation potential of the material and the stage of the acid generation, they do not examine the rate at which the reactivity occurs. To evaluate the rate of reactivity, the third stage of the Klondyke ARD study involved Kinetic Testing.

The static test results indicated mature stages of acid generation for large portions of the two tailings piles; approximately 50 percent of potential acid generation has already occurred (URS, 2003a). For some of the sampling locations, static test results indicated soil pH as low as 2.0. Some metals are more mobile in low-pH conditions and may be leached from the tailings piles at a higher rate. Some of the contaminants of concern, notably arsenic, are influenced by a variety of environmental factors, including pH, redox conditions, solution composition, competing and complexing ions, mineralogy of the aquifer, reaction kinetics, and the hydraulics of the ground water flow system. Arsenic concentrations in ground water tend to increase in higher pH conditions, due to decreased adsorption capacity of iron hydroxide compounds (Welch et al., 1988). During floods, metals in tailings can be eroded and transported downstream, and percolate into groundwater. Introduction of metals into the perennial reach of Aravaipa Creek could potentially impact identified water uses of the creek downstream from the Site.

The metal leaching rates of the tailings piles were determined using kinetic tests. The metal concentrations in biweekly composite leachate were analyzed for at least 14 weeks during the kinetic testing.

The ICP results indicated that arsenic and lead were present in tailings samples at concentrations exceeding the corresponding NR-SRLs. Arsenic was detected at concentrations ranging from 32 to 159 mg/kg, which exceeds the NR-SRL of 10 mg/kg. Lead was detected at concentrations ranging from 1,940 to greater than 10,000 mg/kg, which exceeds the NR-SRL of 800 mg/kg.

#### *7.1.1.3.2 Chemical Migration of Contaminants*

The results indicated there is potential for contaminant metals to mobilize in the tailings piles. Once mobilized, metal ions can be transported by physical processes in fluids, or by chemical processes such as ion exchange or sorption between migrating fluids and soil or migrating/infiltrating fluids and soil pore water. Chemical migration could occur within a migrating fluid system (surface or groundwater) as metal ions are brought into contact and exchange with dissolved ions in water or soil.

In the semi-arid climate at the Site, chemical migration is not likely to occur as readily or be as effective as physical migration. The most likely mode of chemical migration is during a strong storm event where storm water runoff could pick up metal ions from tailings piles, transport the contaminants offsite, and release the metal ions during an exchange with soil or other fluid. Since the



majority of the contaminants of concern are likely to be adsorbed onto soil particles within the tailings piles, control of runoff and erosion will effectively control a significant portion of potential contaminant transport.

## **7.1.2 Receptors**

### **7.1.2.1 Human Receptors**

Human receptors include residents that live on adjacent properties where soil contamination has been documented. Residents exposed to lead- and arsenic-contaminated soil on a regular basis through inhalation, ingestion or dermal contact may develop chronic health problems. The potential for exposure to contaminated water is much less evident. Deep groundwater, which is the primary source of water in the area, appears to be isolated from metal contaminants present in the tailings piles. Surface water runoff that may pick up metals from the tailings piles occurs primarily during storm events, and human receptors are not likely to be exposed to contaminated water on a long-term basis.

### **7.1.2.2 Ecological Receptors**

Potential biotic receptors in the Aravaipa Creek ecological system include aquatic animal species, such as native fish and amphibians; and various terrestrial mammal, bird, and reptile species. Previous workers have focused on assessing the impact on aquatic species because the potential contaminant migration pathways are primarily surface water and groundwater. However, the contaminants present in channel sediments may also impact terrestrial species.

Concentrations of metals in surface water can increase dramatically during storm events when bottom sediments are re-suspended and surface runoff leaches water-soluble metal salts into the creek. Since many fish and amphibian species hatch during the spring when rain events are most common, they may be exposed to higher than normal concentrations of dissolved metals, and lower than normal pH. Although fish and amphibian eggs are relatively tolerant to metal and low pH exposure, egg-sac fry, alevins, and tadpoles are much more sensitive than adults. Therefore, surface water quality conditions that are non-threatening to adult aquatic life could cause adverse effects on juvenile stages of aquatic life.

## **7.1.3 Background Concentrations of Lead and Arsenic**

Extensive sampling of surface and subsurface soils in the study area has not included collecting samples at locations specifically designated as background samples. However, several areas where samples were collected in the immediate vicinity of the site as well as designated background



samples collected during the EPA sampling in 2010 from the borrow area may be considered for evaluation of background concentrations, as follows:

1. An area northwest of the Site in the Laurel Creek alluvial fan (Figure 5: north of the 2450N grid point line and west of the 1350W grid point line) where lead ranges from 210 to 67 mg/kg, with a mean of 108 mg/kg;
2. Subsurface samples collected at 5 and 10 ft bgs at the Site (Figure 10) where lead ranges from 160 to 9.3 mg/kg, with a mean of 44 mg/kg;
3. Samples from Aravaipa Creek upstream of the site (Figures 4 and 7) where lead ranges from 100 to 10 mg/kg, with a mean of 32 mg/kg; and
4. Samples from borrow area where lead ranges from 18 to 26 mg/kg, with a mean of 22 mg/kg.

Arsenic concentrations at these areas vary considerably, and the mean arsenic concentration exceeds the NR-SRL and R-SRL:

1. Arsenic ranges from <10 to 28 mg/kg, with a mean of 13.8 mg/kg;
2. Arsenic ranges from <10 to 35 mg/kg, with a mean of 14.6 mg/kg.

#### **7.1.4 Limits of Study Area**

The study area boundaries can be placed where concentrations of lead are encountered below the R-SRL of 400 mg/kg. As shown on Figure 5, the current extent of lead contamination extends beyond the original WQARF site boundary composed of source area parcels 110-47-003g and 110-47-003h. The northern boundary of the Site can be placed along the northern portion of the Laurel Creek alluvial fan, approximately on a line between grid points 3200N-500E and 2300N-2700W, from the Laurel Creek channel to the Aravaipa Creek channel. Similarly, the eastern end of the study area can be placed at the base of the slope of the low hills that bound the eastern edge of the Aravaipa Creek floodplain. The elevated metals concentrations in the low hill north of the property east of the Site, parcel 110-47-006, resulted from historical milling operations conducted in that area. Therefore, the study area boundary should be placed east of that low hill. The southwest boundary of the study area can be placed in the Aravaipa Creek channel. Due to site access restrictions, the adjacent property east of the Site situated south of 800N and east of 0W, located in parcel 110-47-004 could not be sampled (Figure 2).



## **8.0 LAND AND WATER USE EVALUATION**

### **8.1 REASONABLY FORESEEABLE LAND USE**

#### **8.1.1 Land Use Planning and Zoning**

According to the Graham County Assessor's Office there are 16 privately owned properties and two properties owned by the State of Arizona surrounding the Klondyke Tailings WQARF Site. Records from the Graham County Planning and Zoning Department (where available) show the privately owned properties are zoned as residential and range in size from 5 to 100 acres.

#### **8.1.2 Current and Projected Land Use**

ADEQ developed a questionnaire for current and projected land use and mailed it to the current property owners. The questionnaire was designed to obtain input on residential conditions that would allow ADEQ to more accurately understand the current and projected land and water use of the area. Six residents returned completed questionnaires to ADEQ. Of the six, one property owner, the owner of parcels 110-47-003g and 110-47-003h indicated that he is currently using his property for grazing. Two property owners, parcels 110-47-001i and 110-47-001m, described their current land use as residential and grazing. The remaining respondents stated their current land use as residential.

The ADEQ questionnaires asked the current property owners of any future plans to develop new structures on their property, add extensions to the current structures, or to change the current usage of the properties. The owners of parcel 110-47-006 indicated they were planning an extension to the current structure. The owners of parcels 110-47-003f and 110-47-003d expressed interest in constructing additional homes on their properties for resale. The owners of parcel 110-47-001i indicated they were considering constructing a home and outbuildings on their property. The owner of parcels 110-47-003g and 110-47-003h will possibly build a home on his property. Returned questionnaires are included in Appendix H.

### **8.2 REASONABLY FORESEEABLE WATER USE**

#### **8.2.1 Available Water Resources**

According to the ADWR website there are currently no existing Certificates of Convenience and Necessity (CC&Ns) in the Klondyke area. A CC&N is required by any person or entity who desires to construct and or operate a water utility in the State of Arizona. The residents of Klondyke depend solely on privately owned wells for their domestic purposes.



## **8.2.2 Beneficial Uses of Water**

Beneficial uses of water in the Klondyke area are drinking water, water supply, irrigation, and livestock.

## **8.2.3 Current and Projected Water Use**

According to the responses to the ADEQ questionnaire, the current property owners at Klondyke use their well water for water supply, domestic purposes, irrigation, and livestock. Projected water use according to the questionnaires will be water supply for new or additional residences, drinking water, irrigation and gardening.

## **8.2.4 Water Supply**

Water supply is the process of self-provision or provision by third parties of water of various qualities to different users, excluding irrigation. The water supply system for each Klondyke residence consists of a water supply well that pumps groundwater from an underground aquifer. Well water is most likely filtered within the household and used for drinking and bathing. Outside the household, water is used for livestock and irrigation.

## **8.2.5 Additional Sources of Water Supply**

There are currently no additional water supply sources in the Klondyke area. Residents currently depend solely on groundwater and, if additional water is needed, new wells will be installed.



## **9.0 SCREENING-LEVEL HUMAN HEALTH RISK ASSESSMENT**

### **9.1 INTRODUCTION**

A screening-level human health risk assessment (HHRA) was performed to identify metals in each exposure area that could pose a threat to human health, based on current and potential future land use scenarios.

### **9.2 DATA USED IN THE HHRA**

Data available for the risk assessment are described in Sections 6.2 and 6.3. All available data analyzed by EDXRF were used in the risk assessment, except for arsenic results because they were not considered usable (URS, 2012). All available data analyzed by fixed-based laboratory were used in the risk assessment.

### **9.3 EXPOSURE ASSESSMENT**

This section identifies the exposure areas, Conceptual Site Model (CSM), human health exposure scenarios, and exposure point concentrations to be used in the screening-level HHRA.

#### **9.3.1 Exposure Areas**

The Klondyke site consists of 13 parcels each of which is private property (Figure 2). The 10-acre main site which contains the source areas (historical tailings piles) consists of a portion of a large parcel (110-47-003g) and a portion of a much smaller parcel (110-47-003h), each belonging to the same property owner. Each parcel will be evaluated as a separate exposure area in the screening-level HHRA.

#### **9.3.2 Land Use and Potentially Exposed**

Seven of the parcels (110-47-001f, 110-47-001g, 10-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, and 10-47-006) currently have residents living on the properties. Two additional parcels (110-47-001b, 110-47-001k, and 110-47-004) are considered residential, but do not currently have residents living on the property. Parcel 110-47-003f does contain a church, but the owner of the property spends some time in residence on the parcel.

The main site consists of a portion of parcel 110-47-003g and a portion of parcel 110-47-003h which are owned by the same property owner and are not currently considered residential. The southern portion of parcel 110-47-003g is not fenced. To be protective, future land use was assumed to be residential for all of the parcels. In addition, future construction work is considered to be a potential



scenario for all of the parcels, anticipating that construction would be a necessary precursor to future residential (or other) use of parcels.

### **9.3.3 Conceptual Site Model**

The CSM (Figure 22) is a schematic representation of source areas, release mechanisms, environmental transport media, and potential exposure routes for contaminants that may lead to exposure of human receptors to contaminants. The purpose of the CSM is to identify contaminant sources and exposure pathways that are anticipated to result in the most exposure for the identified receptors.

The primary sources of contamination in the area are the upper and Lower Tailings Piles. Potential sources of contamination are the historical milling activities and the Dog Water mine tailings on parcel 110-47-006. The Grand Reef Mine tailings and waste rock are another source of contamination upstream along Laurel Creek. Secondary sources of contamination are storm events that erode and transport tailings material, outdoor dust (particulates), onsite soil and subsurface soil.

The types of media that are affected are; soil, stream sediments, surface water and possibly groundwater. However, groundwater in the area does not currently show any effects from the contaminated soils at the surface. The types of contaminants in each medium are metals such as antimony, arsenic, cadmium, copper, lead, manganese, mercury, vanadium, and zinc.

The main concerns for the public health and the ecology at and in the vicinity of the Site are:

- high levels of antimony, arsenic, cadmium, copper, lead, manganese, mercury, vanadium, and zinc detected at concentrations exceeding the R-SRLs in the tailings piles;
- acid generation in the tailings piles that could mobilize metals into Aravaipa Creek sediments and surface water through local erosion and flooding;
- migration of metals into the underlying groundwater;
- potential for contaminants migrating downstream in surface water and down gradient in groundwater to impact the Aravaipa Canyon Wilderness Area.

There are several groups of humans who may come in contact with one or more of the contaminated environmental media at and in the vicinity of the Site including the current residents; recreational users such as hikers, campers, and swimmers; persons enjoying outdoor activities such as fishing or riding ATVs; future residents; and road or other construction workers. Exposure routes for humans may include one or a combination of ingestion, inhalation, or dermal contact depending on the type



of activity. Biota in the area that may be affected include family pets, livestock, fish, birds, wildlife, and vegetation, and the exposure routes may include ingestion, inhalation, or dermal contact.

Potentially complete and significant exposure pathways are evaluated in HHRAs. A complete exposure pathway includes all of the following elements:

- A source and mechanism of contaminant release,
- A transport or contact medium (e.g., soil, groundwater, or air),
- An exposure point where humans can contact the contaminated medium, and
- An exposure (intake) route (such as ingestion or inhalation).

### ***9.3.3.1 Potential Exposure Media***

Potential exposure media in each parcel includes surface soil (0 to 3 inches bgs) and subsurface soil (6 inches to 10 feet bgs), groundwater, and air. The majority of subsurface samples (including all subsurface soil samples analyzed by EDXRF) were collected at depths ranging from 6 to 24 inches bgs). However, 27 subsurface soil samples collected at depths of 1, 5 or 10 feet bgs in Parcel 110-47-003g and analyzed by fixed-base laboratory were included in the subsurface soil dataset evaluated in the risk assessment. In addition, surface water and sediment in Aravaipa and Laurel Creek are potential exposure media in parcels through which the Creeks pass. Residents and site visitors could be exposed to surface soil. Exposure to subsurface soil may occur during or after future site excavation work. Residents and site visitors could be exposed to subsurface soil brought to the surface by excavation activities. Direct exposure to groundwater will not occur during excavation work, because the depth to groundwater ranges from approximately 46 to approximately 52 feet bgs (much deeper than anticipated excavation depth of 10 to 15 feet bgs). However, groundwater is currently used as a source of drinking water in some of the parcels. To be protective, future use of groundwater as a source of drinking water was assumed to occur in each parcel. However, there is no information to suggest that groundwater beneath the Site has been impacted by the tailings piles. For this reason, groundwater will not be considered to be an affected media in the screening-level HHRA. Surface water and sediments are potential exposure media for residents and site visitors in parcels 110-47-001i, 110-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, 110-47-003h, and 110-47-003g. Surface water at the site is intermittent and analytical results for surface water do not exceed the corresponding surface water regulations for Aravaipa Creek. Therefore, surface water will not be considered to be an affected media in the screening-level HHRA.



### 9.3.3.2 *Potential Human Receptors*

Based on current and reasonably anticipated future land use scenarios, current/future residents exposed to surface soil and subsurface soil (brought to the surface during excavation activities) were evaluated in the screening-level HHRA. This exposure scenario is protective (i.e., has greater exposure and risk) of other potential human exposure scenarios such as site visitors (assumed to be recreational users such as campers, hikers, swimmers, mountain bikers, along with possible fishing and ATV activities) or construction workers exposed to surface and subsurface soil, which also are considered potentially complete scenarios.

### 9.3.3.3 *Potentially Complete and Significant Exposure Pathways*

Potentially complete and significant pathways are shown below.

#### **Current/Future Residents:**

- Ingestion, dermal, and inhalation (of particulates) exposure to surface soil (0 to 3 inches bgs).
- Ingestion, dermal, and inhalation (of particulates) exposure to subsurface soil (6 inches to 10 feet bgs) (brought to the surface during excavation activities).
- Ingestion, dermal, and inhalation (of particulates) exposure to dry surface sediments (0 to 3 inches).

#### **Current/Future Site Visitors:**

- Ingestion, dermal, and inhalation (of particulates) exposure to surface soil (0 to 3 inches bgs).
- Ingestion, dermal, and inhalation (of particulates) exposure to subsurface soil (6 inches to 10 feet bgs) (brought to the surface during excavation activities).
- Ingestion, dermal, and inhalation (of particulates) exposure to dry surface sediments (0 to 3 inches bgs).

#### **Future Construction Workers:**

- Ingestion, dermal, and inhalation (of particulates) exposure to surface soil (0 to 3 inches bgs) and subsurface soil (6 inches to 10 feet bgs) during excavation activities.

Domestic use of groundwater by residents and recreational exposure to surface water by residents and site visitors were not evaluated in the screening-level HHRA because those media are not considered to be affected by the site.



#### **9.3.3.4 Potentially Complete, but Negligible Pathways**

EPA's risk assessment and risk characterization guidance (EPA 1989, 1992) does not require that all plausible exposure scenarios and exposure pathways be assessed. Pathways that are incomplete or potentially complete, but negligible, are not quantified in the risk assessment. A pathway may be potentially complete but negligible if the transport process is considered to be insignificant resulting in negligible concentrations of contaminants in the exposure medium, or if the amount of exposure to the medium is considered to be negligible. Potentially complete, but negligible, pathways were not evaluated in the screening-level HHRA because these pathways would be unlikely to measurably impact risk estimates and thus would be unlikely to impact future site removal action decisions. Potentially complete pathways that are not evaluated quantitatively in the risk characterization are discussed qualitatively in the uncertainty section of the screening-level HHRA.

Construction worker exposure to surface sediments is considered to be negligible because construction work will not occur in a creek. The infrequent (if any) exposure to sediments that might occur during construction activities is considered to be negligible.

#### **9.3.3.5 Incomplete Pathways**

Incomplete pathways were not evaluated in the screening-level HHRA because there is no potential risk when there is no potential exposure to contaminants. Direct exposure to groundwater and surface water are incomplete pathways, because those media have not been affected by the site.

### **9.3.4 Exposure Point Concentrations**

Maximum detected concentrations (MDCs) of each metal in each parcel were used as the exposure point concentrations (EPCs). For surface soil and subsurface soil, EDXRF results were available for antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc. The Final Site Characterization Report (SCR) (URS, 2013) has demonstrated acceptable correlations between EDXRF and fixed-base laboratory results for cadmium, lead, and manganese. The SCR stated that only the non-detect (<10 mg/kg) EDXRF data for arsenic is usable (URS, 2013). Therefore, EDXRF results for arsenic in surface and subsurface soil were not used in the screening-level HHRA. Although direct evidence of correlation is available for only three metals, the EDXRF results (which are much more plentiful and therefore provide a more robust data set for risk assessment) for the other 9 metals in surface and subsurface soil were used in the screening-level HHRA.

In addition, fixed-base laboratory results were available for a subset of surface and subsurface soil samples for aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium,



cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, vanadium, zinc, and cyanide. Calcium, iron, magnesium, potassium, and sodium were not evaluated in the screening-level HHRA, because they are essential macro-nutrients that do not have R-SRL values. Fixed-base laboratory results for the other 20 metals and cyanide in surface and subsurface soil were used in the screening-level HHRA.

## **9.4 TOXICITY ASSESSMENT**

The toxicity values used in screening-level HHRA are the values that were used to develop the current ADEQ (2007) soil remediation levels (SRLs). Some of these toxicity values may be out-of-date, because EPA updates their toxicity values more frequently (every 6 months) than ADEQ updates the SRLs (not since 2007).

## **9.5 SCREENING LEVEL RISK EVALUATION – IDENTIFICATION OF CHEMICALS OF CONCERN**

Risk was evaluated in each parcel by identifying contaminants of potential concern. COPCs are chemicals with MDCs in surface soil, subsurface soil, or surface sediments that exceed ADEQ SRLs for residential soil. Parcels and creeks containing media where COPCs are identified have the potential to pose an unacceptable threat to human health. Parcels and creeks that do not contain media with COPCs are unlikely to pose a threat to human health.

### **9.5.1 Soil in Parcels**

An initial site-wide screen was done to eliminate metals in soil that did not exceed R-SRLs at any locations on the Site. Metals that exceeded R-SRLs in surface soil or subsurface soil in at least one parcel (key metals) included in Tables 4 through 7. For surface and subsurface soil, both EDXRF and fixed-based laboratory data were screened for antimony, cadmium, chromium, copper, lead, manganese, mercury, nickel, and zinc. Only fixed-based laboratory data were screened for aluminum, arsenic, barium, beryllium, boron, cobalt, cyanide, molybdenum, selenium, silver, thallium, and vanadium in surface soil.

Site-wide EDXRF results for antimony, cadmium, copper, lead, manganese, mercury, and zinc in surface soil exceeded R-SRLs. EDXRF results for arsenic in surface soil were not considered usable. Site-wide EDXRF results for chromium and nickel in surface soil were less than R-SRLs (and therefore less than NR-SRLs). Site-wide fixed-based laboratory results for arsenic, cadmium, copper, lead, manganese, vanadium, and zinc in surface soil exceeded R-SRLs. Site-wide fixed-based laboratory results for aluminum, antimony, barium, beryllium, boron, chromium, cobalt, mercury,



molybdenum, nickel, selenium, silver, thallium, and cyanide in surface soil were less than R-SRLs (and therefore less than NR-SRLs).

The results of the site-wide screen in subsurface soil were nearly identical to those in surface soil. The only overall difference was that vanadium was not analyzed for in subsurface soil. Based on the site-wide screen for surface and subsurface soil, antimony, arsenic, cadmium, copper, lead, manganese, mercury, vanadium (surface soil only), and zinc are the key metals that will be evaluated further in each parcel in the screening-level HHRA. Aluminum, barium, beryllium, boron, chromium, cobalt, molybdenum, nickel, selenium, silver, thallium, and cyanide were not evaluated further in the screening level HHRA.

MDCs for surface and subsurface soil in each parcel are shown in Tables 4 to 7. The results of the comparison of MDCs to ADEQ screenings levels in surface soil are summarized in Table 19. The parcels in Table 19 are ordered based, to the degree possible, from least to most contamination and potential risk.

#### **9.5.1.1 PARCEL 110-47-001f**

Antimony was the only COC identified in Parcel 110-47-001f. Concentrations of antimony slightly exceeded the R-SRL of 31 mg/kg in one surface soil sample analyzed by EDXRF. The concentrations of antimony in all other surface samples analyzed by EDXRF were either non-detect or were detected at concentrations lower than the R-SRL. EDXRF and fixed-based laboratory results were not available for antimony in subsurface soil.

Parcel 110-47-00f is the only parcel evaluated where the MDC of lead in surface soil analyzed by EDXRF and fixed-based laboratory did not exceed the R-SRL of 400 mg/kg. Usable results for arsenic were not available in Parcel 110-47-00f.

No EDXRF or fixed-based laboratory samples were analyzed for subsurface soil in this parcel.

#### **9.5.1.2 PARCEL 110-47-001b**

Lead was the only COC identified in Parcel 110-47-001b. Concentrations of lead slightly exceeded the R-SRL of 400 mg/kg in one surface soil sample analyzed by EDXRF and one surface soil sample analyzed by fixed-based laboratory. Lead concentrations ranged from 120 to 250 mg/kg in the other five surface soil samples analyzed by EDXRF. The MDC for lead in subsurface soil analyzed by EDXRF of 150 mg/kg is well below the R-SRL. Arsenic was detected in one surface soil sample analyzed by fixed-based laboratory at a concentration below the R-SRL.

No fixed-based laboratory samples were analyzed for subsurface soil in this parcel.



**9.5.1.3 PARCEL 110-47-001h**

Lead was the only COC identified in Parcel 110-47-001h. The MDC of lead in surface soil of 750 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 580 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but did not exceed the NR-SRL of 800 mg/kg. Only 4 of 37 surface soil samples (11%) analyzed by EDXRF had concentrations of lead exceeding the R-SRL. Only one subsurface soil sample analyzed by EDXRF exceeded the R-SRL.

Usable results for arsenic were not available in Parcel 110-47-00h.

No fixed-based laboratory samples were analyzed for subsurface soil in this parcel.

**9.5.1.4 PARCEL 110-47-001k**

Lead was the only COC identified in Parcel 110-47-001k. A concentration of lead of 2,500 mg/kg exceeded the R-SRL in one surface soil sample analyzed by EDXRF; however, in the only other surface soil sample analyzed by EDXRF, the lead concentration of 79 mg/kg was less than the R-SRL. No fixed-based laboratory samples were available for lead in surface soil or subsurface soil in 110-47-K.

Usable results for arsenic were not available in Parcel 110-47-001k.

No fixed-based laboratory samples were analyzed for surface soil or subsurface soil in this parcel.

**9.5.1.5 PARCEL 110-47-001g**

Lead was the only COC identified in Parcel 110-47-001g. The MDC of lead in surface soil of 1,700 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 1,200 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL of 400 mg/kg and the NR-SRL of 800 mg/kg.

Approximately 50% of the surface soil samples analyzed by EDXRF in Parcel 110-47-001g had lead concentrations higher than the R-SRL, and 30% were higher than the NR-SRL.

Usable results for arsenic were not available in Parcel 110-47-001g.

No fixed-based laboratory samples were analyzed for surface soil or subsurface soil in this parcel.

**9.5.1.6 PARCEL 110-47-003d**

Lead, arsenic, and antimony were identified as COPCs in Parcel 110-47-003d. The MDC of lead in surface soil of 1,500 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of



2,700 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 73% of the surface soil samples analyzed by EDXRF in Parcel 110-47-003d had lead concentrations higher than the R-SRL and 25% were higher than the NR-SRL. The MDC for antimony in subsurface soil exceeded the R-SRL of 31 mg/kg, but did not exceed the NR-SRL of 410 mg/kg.

The MDCs of arsenic in surface soil analyzed by fixed-base laboratory of 11 mg/kg slightly exceeded the R-SRL and NR-SRL of 10 mg/kg.

No fixed-based laboratory samples were analyzed for subsurface soil in this parcel.

#### **9.5.1.7 PARCEL 110-47-003f**

Lead, antimony, and mercury were identified as COPCs in Parcel 110-47-003f. The MDC of lead in surface soil of 2,200 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 1,900 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 78% of the surface soil samples analyzed by EDXRF in Parcel 110-47-003f had lead concentrations higher than the R-SRL, and approximately 39% were higher than the NR-SRL.

The concentration of arsenic in the only subsurface soil sample analyzed by fixed-base laboratory of 9.2 mg/kg was slightly lower than the R-SRL and NR-SRL.

The MDCs for antimony and mercury in surface soil analyzed by EDXRF did not exceed the R-SRLs. The MDC of antimony in subsurface soil analyzed by EDXRF of 46 mg/kg exceeded the R-SRL, but did not exceed the NR-SRL. The MDC of mercury in subsurface soil analyzed by EDXRF of 24 mg/kg slightly exceeded the R-SRL of 23 mg/kg, but did not exceed the NR-SRL of 310 mg/kg.

No fixed-based laboratory samples were analyzed for surface soil in this parcel.

#### **9.5.1.8 PARCEL 110-47-001m**

Lead, arsenic, antimony, cadmium, and mercury were identified as COPCs in Parcel 110-47-001m. The MDC of lead in surface soil of 2,200 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 3,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 46% of the surface soil samples analyzed by EDXRF in Parcel 110-47-001m had lead concentrations higher than the R-SRL, and approximately 24% were higher than the NR-SRL.



The MDCs of arsenic analyzed by fixed-base laboratory in surface soil analyzed of 40 mg/kg and in subsurface soil of 31 mg/kg each exceeded the R-SRL and NR-SRL of 10 mg/kg.

The MDCs for antimony, cadmium, and mercury in surface soil analyzed by EDXRF did not exceed the R-SRLs. The MDC of antimony in subsurface soil analyzed by EDXRF of 43 mg/kg exceeded the R-SRL, but did not exceed the NR-SRL. The MDC of cadmium in subsurface soil analyzed by EDXRF of 94 mg/kg exceeded the R-SRL of 39 mg/kg, but did not exceed the NR-SRL of 510 mg/kg. The MDC of mercury in subsurface soil analyzed by EDXRF of 50 mg/kg exceeded the R-SRL, but did not exceed the NR-SRL.

#### **9.5.1.9 PARCEL 110-47-001i**

Lead, arsenic, antimony, and mercury were identified as COPCs in Parcel 110-47-001i. The MDC of lead in surface soil of 2,600 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 6,100 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 53% of the surface soil samples analyzed by EDXRF in Parcel 110-47-001i had lead concentrations higher than the R-SRL, and approximately 35% were higher than the NR-SRL.

The MDCs of arsenic analyzed by fixed-base laboratory in surface soil of 29 mg/kg and in subsurface soil of 14 mg/kg each exceeded the R-SRL and NR-SRL of 10 mg/kg

The MDC of antimony in surface soil of 59 mg/kg for samples analyzed by EDXRF and of antimony in subsurface soil of 68 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL. The MDC of mercury in surface soil of 31 mg/kg for samples analyzed by EDXRF and of mercury in subsurface soil of 45 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL.

#### **9.5.1.10 PARCEL 110-47-003b**

Lead, arsenic, antimony, and mercury were identified as COPCs in Parcel 110-47-003b. The MDC of lead in surface soil of 3,700 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 7,200 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 69% of surface soil samples analyzed by EDXRF in Parcel 110-47-003b had lead concentrations higher than the R-SRL, and approximately 34% were higher than the NR-SRL.

The MDCs of arsenic analyzed by fixed-base laboratory in surface soil of 54 mg/kg and in subsurface soil of 19 mg/kg each exceeded the R-SRL and NR-SRL of 10 mg/kg.

The MDC of antimony in surface soil of 37 mg/kg for samples analyzed by EDXRF and of antimony in subsurface soil of 90 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not



the NR-SRL. The MDC of mercury in surface soil of 49 mg/kg for samples analyzed by EDXRF and of mercury in subsurface soil of 48 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL.

#### **9.5.1.11 PARCEL 110-47-003h**

Lead, arsenic, antimony, and mercury were identified as COPCs in Parcel 110-47-003h. The MDC of lead in surface soil of 11,000 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 2,800 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 90% of surface soil samples analyzed by EDXRF in Parcel 110-47-003h had lead concentrations higher than the R-SRL, and approximately 74% were higher than the NR-SRL.

The MDC of arsenic analyzed by fixed-base laboratory in surface soil of 20 mg/kg exceeded the R-SRL and NR-SRL of 10 mg/kg.

The MDC of antimony in surface soil of 50 mg/kg for samples analyzed by EDXRF and of antimony in subsurface soil of 37 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL. The MDC of mercury analyzed by EDXRF in surface soil of 47 mg/kg exceeded the R-SRL, but not the NR-SRL. However, the MDC of mercury analyzed by EDXRF in subsurface soil did not exceed the R-SRL.

No fixed-based laboratory samples were analyzed for subsurface soil this parcel.

#### **9.5.1.12 PARCEL 110-47-006**

Lead, arsenic, antimony, cadmium, copper, mercury, manganese, and zinc were identified as COPCs in Parcel 110-47-006. The MDC of lead in surface soil of 18,000 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 18,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SR. Approximately 50% of surface soil samples analyzed by EDXRF in Parcel 110-47-006 had lead concentrations higher than the R-SRL, and approximately 29% were higher than the NR-SRL.

The MDCs of arsenic analyzed by fixed-base laboratory in surface soil of 65 mg/kg and subsurface soil of 240 mg/kg exceeded the R-SRL and NR-SRL of 10 mg/kg.

The MDC of antimony in surface soil of 120 mg/kg for samples analyzed by EDXRF and of antimony in subsurface soil of 86 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL. The MDC of cadmium in surface soil of 1,400 mg/kg for samples analyzed by EDXRF exceeded the R-SRL and the NR-SRL. The MDC of cadmium in subsurface soil of 390 mg/kg for samples analyzed by EDXRF exceeded the R-SRL, but not the NR-SRL. The MDC



of copper in surface soil of 3,200 mg/kg for samples analyzed by EDXRF exceeded the R-SRL of 3,100, but did not exceed the NR-SRL of 41,000. The MDC of copper in subsurface soil does not exceed the R-SRL. The MDC of manganese in surface soil of 6,200 mg/kg for samples analyzed by EDXRF and of manganese in subsurface soil of 5,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL of 3,300, but did not exceed the NR-SRL of 32,000 mg/kg. The MDC of mercury in surface soil did not exceed the R-SRL. The MDC of mercury in subsurface soil of 240 mg/kg for samples analyzed by EDXRF exceeded the R-SRL, but not the NR-SRL. The MDC of zinc in surface soil of 96,000 mg/kg for samples analyzed by EDXRF and of zinc in subsurface soil of 77,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL of 23,000, but not the NR-SRL of 310,000.

#### **9.5.1.13 PARCEL 110-47-003g**

Lead, arsenic, antimony, cadmium, copper, manganese, mercury, vanadium, and zinc were identified as COPCs in Parcel 110-47-003g. The MDC of lead in surface soil of 50,000 mg/kg for samples analyzed by EDXRF and of lead in subsurface soil of 26,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL and the NR-SRL. Approximately 81% of surface soil samples analyzed by EDXRF in Parcel 110-47-003g had lead concentrations higher than the R-SRL, and approximately 72% were higher than the NR-SRL.

The MDCs of arsenic analyzed by fixed-base laboratory in surface soil of 310 mg/kg and subsurface soil of 140 mg/kg exceeded the R-SRL and NR-SRL of 10 mg/kg.

The MDC of antimony in surface soil of 110 mg/kg for samples analyzed by EDXRF and of antimony in subsurface soil of 48 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL. The MDC of cadmium in surface soil of 320 mg/kg for samples analyzed by EDXRF and of cadmium in subsurface soil of 67 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL. The MDC of copper in surface soil of 15,000 mg/kg for samples analyzed by EDXRF and of copper in subsurface soil of 5,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL. The MDC of manganese analyzed by EDXRF in surface soil of 5,700 mg/kg exceeded the R-SRL, but not the NR-SRL. The MDC of manganese in subsurface soil of 68,000 mg/kg for samples analyzed by EDXRF exceeded the R-SRL and the NR-SRL. The MDC of mercury in surface soil of 230 mg/kg for samples analyzed by EDXRF exceeded the R-SRL, but not the NR-SRL. Mercury was not detected in subsurface soil samples analyzed by EDXRF. The MDC of zinc in surface soil of 81,000 mg/kg for samples analyzed by EDXRF and of zinc in subsurface soil of 33,000 mg/kg for samples analyzed by EDXRF each exceeded the R-SRL, but not the NR-SRL.



The MDC of vanadium analyzed by fixed-base laboratory in surface soil of 130 mg/kg exceeded the R-SRL of 78 mg/kg, but not the NR-SRL of 1,000 mg/kg. Vanadium was not analyzed by fixed-base laboratory in subsurface soil or by EDXRF in surface or subsurface soil.

## **9.5.2 Sediments in Creeks**

### **9.5.2.1 Aravaipa Creek**

The MDC for lead analyzed in sediments by EDXRF of 100 mg/kg prior to the 2006 flood did not exceed the R-SRL. The MDC for lead analyzed in sediments by EDXRF of 740 mg/kg after the flood exceeded the R-SRL of 400 mg/kg, but not the NR-SRL of 800 mg/kg (Table 6). The MDC for lead analyzed in sediments by fixed-based laboratory was 95 mg/kg prior to the 2006 flood. The MDC for lead analyzed by fixed-based laboratory in sediments of 1,300 mg/kg after the flood exceeded both the R-SRL and NR-SRL (Table 7).

The MDC for arsenic analyzed in sediments by fixed-based laboratory was non-detect (<8.9 mg/kg) prior to the 2006 flood. The MDC for arsenic analyzed in sediments by fixed-based laboratory of 11 mg/kg after the flood exceeded both the R-SRL and NR-SRL (each 10 mg/kg) (Table 7).

### **9.5.2.2 Laurel Creek**

The MDC for lead analyzed in sediments by EDXRF was 1,300 mg/kg prior to the 2006 flood and 2,100 mg/kg after the flood (Table 6). Both of those MDCs for lead in sediments exceed both the R-SRL and NR-SRL. The MDC for lead in sediments analyzed by fixed-based laboratory of 590 mg/kg prior to the 2006 flood exceeded the R-SRL, but not the NR-SRL. The MDC for lead in sediments analyzed by fixed-based laboratory of 1,700 mg/kg after the flood exceeded both the R-SRL and NR-SRL (Table 7).

The MDCs for arsenic analyzed in sediments by fixed-based laboratory of 12 mg/kg prior to the 2006 flood and 32 mg/kg after the flood each exceed both the R-SRL and NR-SRL (Table 7).

## **9.6 UNCERTAINTY IN THE SCREENING-LEVEL HHRA**

Uncertainties are inherent in the risk assessment process because of the numerous assumptions that are made in estimating exposure, toxicity, and potential risk. Per EPA guidance (EPA, 1989), conservative assumptions are made throughout the risk assessment process so as not to underestimate potential risk. On the other hand, some uncertainties may contribute to underestimating exposure and risk. The HHRA must include an evaluation of uncertainties related to the risk assessment in order to place the risk estimates in perspective and to support risk-based decision-making.



Reasonable conservative assumptions were used in this screening-level HHRA so as not to underestimate potential risks. Some of the sources of potential uncertainty applicable to this screening-level HHRA are described below. The discussion identifies factors and assumptions that contribute to uncertainty and assesses their potential impact on the screening-level HHRA.

### **9.6.1 Data Usability**

EDXRF sampling results for antimony, cadmium, copper, lead, manganese, mercury, and zinc were the primary data used to perform the screening-level HHRA and were the primary basis for the conclusions regarding risk in parcels at the site. Fixed-based laboratory data for these metals were available in some parcels, but the number of fixed-based laboratory results was limited and these data were not necessarily representative of the nature and extent of contamination in the parcels. Good correlations have been established at this site between EDXRF and fixed-based laboratory sampling results for cadmium, lead, and manganese (URS, 2013). EDXRF results for arsenic were not considered usable. No correlations were developed for EDXRF and fixed-based laboratory results for antimony, copper, mercury, and zinc. Therefore, it is not known whether the EDXRF results for antimony, copper, mercury, and zinc used in the screening-level HHRA are realistic estimates of the concentrations in soil at the site, or are too high, or are too low. However, this data usability issue for antimony, copper, mercury, and zinc did not impact the overall conclusions for the screening-level HHRA since the conclusions were primarily based on concentrations of lead analyzed by EDXRF in surface and subsurface soil at the site. Because a good correlation exists between concentrations of lead analyzed in surface soil by EDXRF and fixed-based laboratory, it is valid to base the screening-level HHRA conclusions primarily on the EDXRF sampling results for lead.

The only arsenic data available for the screening-level HHRA were fixed-based laboratory results. As discussed above, the number of fixed-based laboratory results was limited and these data were not necessarily representative of the nature and extent of contamination in the parcels. Therefore, it is difficult to draw conclusions regarding risks to human health from exposure to arsenic in soil in parcels at the site. For example, no arsenic sampling results were available for surface soil in parcels 110-47-001f, 110-47-001h, 110-47-001k, 110-47-001g, and 110-47-003f. No arsenic sampling results were available for subsurface soil in parcels 110-47-001f, 110-47-001b, 110-47-001h, 110-47-001k, 110-47-001g, 110-47-003d, and 110-47-003h. Fixed-based laboratory results were available for arsenic in surface soil in 110-47-001b and subsurface soil in 110-47-003f. In both cases the arsenic concentration was less than the R-SRL, but only a single sampling location was analyzed for arsenic. That lack of comprehensive arsenic sampling results is less problematic for parcels where lead in surface soil would clearly pose a risk to current or potential future residents (110-47-001g, 110-47-003b, 110-47-003g, 110-47-003h, 110-47-003d, 110-47-003f, 110-47-001i,



110-47-006, 110-47-001k, 110-47-001m). Based on data for metals other than arsenic, surface soil in parcels 110-47-001f, 110-47-001b, and 110-47-001h may not pose a risk to current or future residents. However, the potential impacts of arsenic in surface soil for current or future residents is not known for those three parcels.

Vanadium was only analyzed in 110-47-003g, at just a limited number of locations, and only by fixed-based laboratory. The MDC for vanadium in 110-47-003g exceed the R-SRL.

### **9.6.2 Exposure Assessment**

Per common practice for screening-level HHRAs, the risk was evaluated by comparing MDCs to risk-based screening levels. The use of an MDC as the EPC is very conservative and could lead to an overestimate of risk. For example, an MDC could exceed an R-SRL in an exposure area where only 1% of the sampling result, exceed the R-SRL. In such a case, it is likely that the use of more realistic EPCs (such as 95% UCLs for all metals except for lead or arithmetic means for lead) would result in a conclusion of no unacceptable risk to current or future residents. For this reason, EDXRF results for lead were further evaluated in each parcel. In the 10 parcels thought to pose a risk to human health, MDCs exceeded both the R-SRL and NR-SRL and there were numerous additional locations that exceeded either only the R-SRL or both the R-SRL and NR-SRL. Therefore it is very likely that, had the arithmetic mean concentration been used as the EPC for lead in surface soil in the ten parcels instead of the MDC, the results would still have indicated a risk to current and future residents.

In the screening-level HHRA, it was assumed that the exposure to dry sediments is the same as the EPA default assumptions regarding residential exposure to soil in a yard. This assumption probably resulted in an overestimation of risk from exposure to dry sediments. However, the numerical extent of the overestimation is not known, because the actual amount of exposure to dry sediments is not known and likely would hinge on proximity to occupied residences, as well as other factors.

Parcel 110-47-003f does contain a church, but the owner of the property spends some time in residence on the parcel. This resident may be onsite about the same amount of time as the resident on parcel 110-47-001g. The risks that were evaluated in the screening-level HHRA assumed residential exposure to soil in that parcel. The MDC for lead analyzed by EDXRF in surface soil in Parcel 110-47-003f of 2200 mg/kg exceeded both the R-SRL and NR-SRL. Approximately 39% of the concentrations of lead analyzed by lead in surface soil were higher than the NR-SRL. NR-SRLs are derived to be protective of full-time indoor (outdoor) workers. Therefore, lead in surface soil in Parcel 110-47-003f may pose a risk to full-time workers at the church.



### **9.6.3 Risk Characterization**

There is relatively high certainty in the conclusions of the screening-level HHRA relative to current and potential future residents exposed to soil. That is because R-SRLs were derived using standard EPA default values that are almost universally used in HHRA for residential scenarios. However, there is less certainty regarding risk to construction workers and current/future site visitors. Although NR-SRLs for metals were exceeded in 10 of the parcels, the number of exceedances were low in some of the parcels. In addition, NR-SRLs are typically based on standard EPA default values for indoor (non-construction) workers exposed to soil. Depending on the COC evaluated, the use of NR-SRLs could overestimate or underestimate the risk to construction workers and current/future site visitors.

### **9.6.4 Conclusions Regarding Uncertainty**

Assumptions were made in each step of this screening-level HHRA, which introduced uncertainty into the risk characterization results. While this could potentially lead to an underestimation of risk, the use of numerous conservative (i.e., protective of human health) assumptions probably resulted in a net overestimation of potential risk. Therefore, the results of this assessment are likely to be protective of health despite the inherent uncertainties in the process.

## **9.7 LEAD CLEANUP LEVELS**

URS has developed a technical memorandum that derives soil lead cleanup levels for six residential properties based on a EPA (2011) study of the bioavailability of lead in soil samples that were collected on or near the yards on six residential properties (URS, 2013b). The derived soil screening level of 310 mg/kg will be appropriate for use as the cleanup level for lead in soil.



## **10.0 COMMUNITY INVOLVEMENT PLAN**

### **10.1 COMMUNITY ADVISORY BOARD**

A.R.S. §49-289.03 requires a 5 to 20 member board to be appointed to advise ADEQ and the public of issues, concerns and opportunities related to the investigation and cleanup of a site. The members are to represent a diversified cross-section of the community and meet at least four times per year.

The selection committee met in June 2000 to discuss the selection process and review the Community Advisory Board (CAB) applications. CAB applications were mailed to each Klondyke Tailings Site resident that resided within the Community Involvement Area (CIA). A CAB of 13 members was formed for the Klondyke Tailings WQARF Site in June 2000, and met for the first time on July 27, 2000.

Current CAB members include co-chairs Lynn Skinner and Mark Haberstich with Michael Bryce, Bill Griffin, John Luepke, Noralea Gale, Mark Herrington (County Supervisor for District 1 in Graham County), and Lauralea Bott as regular members and James Palmer, Sam Sollers, and Terry Cooper as alternates.

CABs must meet within 90 days of their selection to elect co-chairs and develop a charter defining operating procedures, membership terms and obligations, and opportunities for public involvement. The CAB also reviews the Community Involvement Plan (CIP) and, if necessary, proposes changes to the plan.

### **10.2 SUMMARY OF PREVIOUS COMMUNITY INVOLVEMENT ACTIVITIES**

In 1998 a notice for the Remedial Investigation Scope of Work, fact sheet, and outline of the CIP and the notice of the site listing on the Registry was published in two consecutive issues of the Eastern Arizona Courier. An ADEQ spokesperson was designated in August.

The CIA was established on July 1, 1999.

In the year 2000 a hazardous substance contamination notice was published in the April newsletter. The fact sheets were distributed in April and interviews with the community members were conducted in November. The information repositories were established in July, at the ADEQ Records Center, Safford City-Graham County Library Reference Section, and the Klondyke County Store. The CAB selection committee was established and disbanded in June when the CAB was selected. The CAB met for the first time in July.



In 2001 fact sheets were distributed in December and interviews with the community members were conducted in November and December.

Fact sheets were distributed in May 2002.

In 2006 fact sheets were distributed in April. The County Store repository closed in 2006 and the BLM Ranger Station in Klondyke was established as the new repository.

### **10.3 COMMUNITY INVOLVEMENT PLAN**

The purpose of the CIP is to provide a process for communication between ADEQ and the public. The CIP ensures public access to project information and allows the public participation in the decision-making process associated with the environmental investigation and remediation of the site. The CIP ensures that residents and other interested parties are informed of the Site progress in a timely and accurate manner. This also allows for two-way communication between the residents and ADEQ.

CIPs are updated when additional information is available. Before the CIP is updated questionnaires are sent to the community and interviews with citizens and stakeholders in the Klondyke CIA are conducted with those who respond to the questionnaires. The CIP is then outlined with the community issues and concerns. The background, historic, and demographic portions of the document are compiled by ADEQ.

The CIP is reviewed annually, as required by Arizona statute (R18-16-404), and revised as necessary. The ADEQ community involvement staff reviews the plan with input from the CAB in response to changes in the project time line and evolving public concerns and information needs.



## 11.0 SUMMARY AND CONCLUSIONS

### 11.1 SUMMARY

#### 11.1.1 Nature and Extent of Contamination

The lateral extent of lead contamination found in surface soils during this investigation was greater than expected. The sample results indicated the potential for a larger area of contamination from historic milling activities, windblown or surface water movement of metals contamination as well as other sources of metal contamination may exist in the vicinity of the Site such as the Grand Reef mine and the tailings on parcel 110-47-006. A possible explanation of the extensiveness of the lead contamination could be the presence of the Grand Reef Mine upstream in Laurel Canyon. Lead and arsenic contamination is present on the Laurel Creek alluvial fan that extends southwestward out of Laurel Canyon. These results indicate that there are two sources of lead and arsenic contamination: the Upper and Lower Tailings Piles; and mineralized rock in Laurel Canyon up gradient from the Site, including waste rock/tailings at and near the abandoned Grand Reef Mine.

#### 11.1.2 Fate and Transport

Elevated levels of lead and arsenic, along with other contaminants of concern, in tailings piles poses a risk of contamination to Aravaipa Creek and shallow ground water resources in the area. The contaminants of concern are largely present as metal ions adsorbed onto clay and mineral particles in the tailings, and are not highly mobile under current conditions. If tailings material is eroded into the creek channel or the surrounding landscape, ion exchange processes could mobilize the contaminants and cause environmental damage.

Water uses in Aravaipa Creek are designated as aquatic and wildlife- warm water; fish consumption; full body contact; and livestock watering. Aravaipa Creek is intermittent in the study area, but becomes a perennial stream approximately two miles from the site.

Protecting the tailings material from wind and water erosion will significantly decrease the potential for environmental contamination from the Klondyke tailings piles.

#### 11.1.3 Screening-Level Risk Assessment Summary

##### 11.1.3.1 Soil in Parcels

Both EDXRF and fixed-based laboratory results were used in the screening-level HHRA. The EDXRF sampling results were more comprehensive (more samples were obtained in each parcel) than the fixed-based laboratory sampling results. Although there is good correlation between



EDXRF and fixed-based laboratory data on a sample-by-sample basis for several analytes, because there were only limited analysis of samples by fixed-based laboratory, the MDCs of metals analyzed by fixed-based laboratory sometimes differed greatly from the MDCs of metals analyzed by EDXRF. For example, the maximum detected concentrations of lead, arsenic, cadmium, copper, manganese, and zinc analyzed by EDXRF in surface soil in Parcel 110-47-006 exceeded their R-SRLs. In the same parcel, only the maximum detected concentrations of lead and arsenic analyzed by fixed-based laboratory in surface soil exceeded their R-SRLs. There were 140 surface soil samples analyzed by EDXRF in Parcel 110-47-006 versus 34 samples of surface soil analyzed by fixed-based laboratory. Therefore, the fixed-based laboratory sampling results are not necessarily representative of the nature and extent of contamination in Parcel 110-47-006. Similarly, fixed-based laboratory sampling results are not necessarily representative of the nature and extent of contamination in the other 12 parcels.

Therefore, EDXRF results were primarily used to evaluate risk for lead, antimony, cadmium, copper, manganese, mercury, and zinc. EDXRF results were not valid for samples where arsenic was detected at concentrations greater than 10 mg/kg and for samples where arsenic was not detected and the reporting limit was greater than 10 mg/kg. No EDXRF sampling results were available for vanadium. Therefore, only fixed-based laboratory results were used to evaluate risks for arsenic and vanadium.

### ***11.1.3.2 Surface Soil***

Current/future residents and future construction workers could be exposed to surface soil in all 13 parcels. Site visitors could be exposed to surface soil in some of the parcels. Risk from exposure to surface soil was evaluated by comparing MDCs of metals to R-SRLs protective of residential exposure and NR-RSLs protective of non-residential exposure.

#### ***11.1.3.2.1 Parcels Where Risk from Exposure to Surface Soil is Present***

The following ten parcels have concentrations of metals in surface soil that would likely pose a risk to current or future residents: 110-47-001g, 110-47-001i, 110-47-001k, 110-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, 110-47-003g, 110-47-003h, and 110-47-006. In all ten parcels, the MDCs of lead analyzed by EDXRF in surface soil exceeded the R-SRL. In addition, each parcel had numerous additional surface soil sampling locations where lead analyzed by EDXRF exceeded the R-SRL. Therefore, based on solely on the evaluation of lead concentrations analyzed by EDXRF, surface soil in the ten parcels would be predicted to pose a risk to current or future residents.

In addition, seven of the parcels had MDCs of arsenic in surface soil analyzed by fixed-based laboratory that exceeded the R-SRL, five of the parcels had MDCs of antimony in surface soil



analyzed by EDXRF that exceeded the R-SRL, and four of the parcels had MDCs of mercury in surface soil analyzed by EDXRF that exceeded the R-SRL. Exceedances of the R-SRL by cadmium, copper, manganese, and zinc in surface soil analyzed by EDXRF were also observed in the two parcels with the highest lead concentrations (110-47-006 and 110-47-003g).

Some of the ten parcels had concentrations of metals in surface soil that might also pose a risk to current or future non-residential receptors. All ten parcels had MDCs of lead analyzed by EDXRF that exceeded the NR-SRL and some of the parcels had numerous additional sampling locations where lead analyzed by EDXRF exceeded the NR-SRL. In addition, seven out of ten of the parcels had MDCs of arsenic analyzed by fixed-based laboratory that exceeded the NR-SRL. The MDC for manganese analyzed by EDXRF in Parcel 110-47-003g and the MDC for cadmium analyzed by EDXRF in Parcel 110-47-006 each exceeded their NR-SRLs. Because the MDC was used as the EPC and there were fewer exceedances of NR-SRLs (as compared to exceedances of R-SRLs) by metal in the ten parcels, it is not as clear based on the screening level risk assessment that surface soil in the ten parcels would pose a threat to non-residential receptors such as current/future site visitors and future construction workers.

#### *11.1.3.2.2 Parcels Where Risk from Exposure to Surface Soil is Uncertain*

Surface soil in Parcels 110-47-001f, 110-47-001b, and 110-47-001h which each had MDCs that exceed R-SRLs may not pose a risk to current or future residents.

Parcel 110-47-001f had MDCs less than R-SRLs for all metals in surface soil analyzed by EDXRF and fixed-based laboratory, except for antimony analyzed by EDXRF (the concentration of antimony in one surface soil sample of 33 mg/kg slightly exceed the R-SRL of 31 mg/kg). The concentrations of antimony in the 13 additional surface soil samples analyzed by EDXRF were <10, 11, 26, and 30 mg/kg. No fixed-based laboratory sampling results were available for antimony in surface soil in Parcel 110-47-001f. Based on the EDXRF sampling results, it is unlikely that exposure to antimony concentrations throughout the entire parcel would pose a risk to residents. Concentrations of lead analyzed in surface soil by EDXRF in Parcel 110-47-001f were all well below the R-SRL. No sampling results were available regarding the concentration of arsenic in surface soil in Parcel 110-47-001f. Therefore, it is not known whether exposure to arsenic in surface soil in Parcel 110-47-001f would pose a risk to human health.

Parcel 110-47-001b had MDCs less than R-SRLs for all metals in surface soil analyzed by EDXRF and fixed-based laboratory, except for lead analyzed by EDXRF and fixed-based laboratory. The concentration of lead in a single surface soil sample analyzed by fixed-based laboratory of 420 mg/kg slightly exceeded the R-SRL of 400 mg/kg. Parcel 110-47-001b had one sample with a concentration of lead in surface soil analyzed by EDXRF of 420 mg/kg, which slightly exceeds the



R-SRL. The concentrations of lead in the 5 additional surface soil samples analyzed by EDXRF of 120, 180, 190, 190, and 250 mg/kg were all below the R-SRLs. Validation studies have shown good agreement between blood lead concentration (PbB) distributions predicted by the Integrated Exposure Uptake Biokinetic (IEUBK) model and observed PbBs at Superfund sites, when the inputs to the model are arithmetic means of the exposure concentrations (Hogan et al. 1998). Therefore, EPA recommends using arithmetic mean concentrations as the EPC for lead when using the IEUBK model. The IEUBK model was used to derive the R-SRL for lead in soil. EPA also recommends using arithmetic average concentrations of lead as EPCs in the Adult Lead Model (ALM) (EPA 2003). The ALM was used to derive the NR-SRL for lead in soil. Therefore, it is appropriate to use the arithmetic mean concentration as the EPC for lead in soil at this site. The arithmetic mean concentration for lead in surface soil analyzed by EDXRF in 110-47-001b of 225 mg/kg is well below the R-SRL, suggesting the exposure to lead in surface soil in 110-47-001b, may not pose a risk to residents. The concentration of arsenic in a single sample of surface soil analyzed by fixed-based laboratory of 6.4 mg/kg is less than the R-SRL. Because there is only one sampling result for arsenic in surface soil, it is not known whether exposure to arsenic in Parcel 110-47-001b would pose a risk to human health.

Parcel 110-47-001h had MDCs less than R-SRLs for all metals in surface soil analyzed by EDXRF and fixed-based laboratory, except for lead analyzed by EDXRF. The concentration of lead in a single surface soil sample analyzed by fixed-based laboratory of 97 mg/kg was less than the R-SRL of 400 mg/kg. Parcel 110-47-001h had an MDC for lead in surface soil analyzed by EDXRF of 750 mg/kg which exceeded the R-SRL. Only four of 37 surface soil samples analyzed by EDXRF had concentrations of lead exceeding the R-SRL. The arithmetic mean concentration for lead in surface soil analyzed by EDXRF in 110-47-001h of 239 is well below the R-SRL, suggesting the exposure to lead in surface soil in 110-47-001h, may not pose a risk to residents. No sampling results were available regarding the concentration of arsenic in surface soil in Parcel 110-47-001h. Therefore, it is not known whether exposure to arsenic in surface soil in Parcel 110-47-001h would pose a risk to human health.

### ***11.1.3.3 Subsurface Soil***

Future construction workers could be exposed to subsurface soil (6 inches to 10 feet bgs) in all 13 parcels. In addition, it was assumed that current/future residents could be exposed to subsurface soil brought to the surface during excavation activities in all 13 parcels. Site visitors could be exposed to subsurface soil brought to the surface in some of the parcels. Risk from exposure to subsurface soil was evaluated by comparing MDCs of metals to R-SRLs protective of residential exposure and NR-RSLs protective of non-residential exposure.



#### 11.1.3.3.1 *Parcels Where Risk from Exposure to Subsurface Soil is Present*

The following nine parcels have concentrations of metals in subsurface soil that would likely pose a risk to current or future residents: 110-47-001g, 110-47-001i, 110-47-001m, 110-47-003b, 110-47-003d, 110-47-003f, 110-47-003g, 110-47-003h, and 110-47-006. In all nine parcels, the MDCs of lead analyzed by EDXRF in subsurface soil exceeded the R-SRL. In addition, each parcel had numerous additional subsurface soil sampling locations where lead analyzed by EDXRF exceeded the R-SRL. Therefore, based on solely on the evaluation of lead concentrations, subsurface soil in the nine parcels would be predicted to pose a risk to current or future residents if subsurface soil was brought to the surface.

In addition, five of the nine parcels had MDCs of arsenic in subsurface soil analyzed by fixed-based laboratory that exceeded the R-SRL, eight of the parcels had MDCs of antimony in subsurface soil analyzed by EDXRF that exceeded the R-SRL, and five of the parcels had MDCs of mercury in subsurface soil analyzed by EDXRF that exceeded the R-SRL. Exceedances of the R-SRL for cadmium, manganese, and zinc in subsurface soil analyzed by EDXRF were also observed in the two parcels with the highest lead concentrations (110-47-006 and 110-47-003g).

Some of the nine parcels had concentrations of metals in subsurface soil that might also pose a risk to current or future non-residential receptors. All nine parcels had MDCs of lead analyzed by EDXRF that exceeded the NR-SRL and some of the parcels had numerous additional sampling locations where lead analyzed by EDXRF exceeded the NR-SRL. In addition, five parcels had MDCs of arsenic analyzed by fixed-based laboratory that exceeded the NR-SRL. Because the MDC was used as the EPC and there were fewer exceedances of NR-SRLs (as compared to exceedances of R-SRLs) by metals in the nine parcels, it is not as clear based on the screening level risk assessment that subsurface soil in the nine parcels would pose a risk to non-residential receptors such as current/future site visitors and future construction workers.

#### 11.1.3.3.2 *Parcels Where Risk from Exposure to Subsurface Soil is Unknown or Uncertain*

Subsurface soil sampling results analyzed by EDXRF or fixed-based laboratory were not available in Parcels 110-47-001f and 110-47-001k. Therefore, the potential risk posed by the concentrations of metals in subsurface soil in these parcels is unknown.

Parcel 110-47-001b had MDCs less than R-SRLs for all metals in subsurface soil analyzed by EDXRF. No fixed-based laboratory sampling results were available for subsurface soil in Parcel 110-47-001b. No sampling results were available regarding the concentrations of arsenic in subsurface soil in Parcel 110-47-001b. Therefore, it is not known whether exposure to arsenic in subsurface soil in Parcel 110-47-001f would pose a risk to human health.



Parcel 110-47-001h had an MDC for lead in subsurface soil analyzed by EDXRF of 580 mg/kg which exceeded the R-SRL. No fixed-based laboratory sampling results were available for subsurface soil in Parcel 110-47-001h. Only one of 81 subsurface soil samples analyzed by EDXRF had concentrations of lead exceeding the R-SRL. The arithmetic mean concentration for lead in subsurface soil analyzed by EDXRF in 110-47-001h of 125 mg/kg is well below the R-SRL, suggesting the exposure to lead in subsurface soil in 110-47-001h, may not pose a risk to residents. No sampling results were available regarding the concentration of arsenic in subsurface soil in Parcel 110-47-001h. Therefore, it is not known whether exposure to arsenic in subsurface soil in Parcel 110-47-001h would pose a risk to human health.

#### ***11.1.3.4 Sediments in Creeks***

##### ***11.1.3.4.1 Aravaipa Creek***

The MDCs for lead in sediments analyzed by EDXRF and fixed-based laboratory prior to the 2006 flood did not exceed the R-SRL. Arsenic analyzed in sediments by fixed-based laboratory was non-detect prior to the 2006 flood.

The MDC for lead analyzed in sediments by EDXRF after the flood exceeded the R-SRL of 400 mg/kg, but not the NR-SRL of 800 mg/kg. However, the MDC for lead analyzed by fixed-based laboratory in sediments after the flood exceeded both the R-SRL and NR-SRL. The MDC for arsenic analyzed in sediments by fixed-based laboratory after the flood exceeded both the R-SRL and NR-SRL.

Concentrations of lead and arsenic in sediments in Aravaipa Creek could pose a risk to residents if exposure to sediments by residents was similar in extent to the EPA's assumption regarding exposure to residential soil. Because the sediments in Aravaipa Creek are generally dry (surface water flow is intermittent), exposure to dry sediments in Aravaipa Creek could be very similar to exposure to soil if Aravaipa Creek were located on an occupied residential property.

##### ***11.1.3.4.2 Laurel Creek***

The MDC for lead analyzed in sediments by EDXRF prior to the 2006 flood exceeded both the R-SRL and NR-SRL. The MDC for lead in sediments analyzed by fixed-based laboratory prior to the 2006 flood exceeded the R-SRL, but not the NR-SRL. The MDC for arsenic analyzed in sediments by fixed-based laboratory prior to the 2006 flood exceeded both the R-SRL and NR-SRL.

The MDC for lead analyzed in sediments by EDXRF and fixed-based laboratory after the flood exceeded the R-SRL and NR-SRL. The MDC for arsenic analyzed in sediments by fixed-based laboratory after the flood exceeded both the R-SRL and NR-SRL.



Concentrations of lead and arsenic in sediments in Laurel Creek could pose a threat to residents if exposure to sediments by residents was similar in extent to the EPA's assumption regarding exposure to residential soil. Because the sediments in Laurel Creek are generally dry (surface water flow is intermittent), exposure to dry sediments in Laurel Creek could be very similar to exposure to soil if Laurel Creek were located on or adjacent to an occupied residential property.

## **11.2 CONCLUSIONS**

The purpose of this RI is to evaluate the nature and extent of metal contamination in soil, sediment, groundwater and surface water at and in the vicinity of the Site and to characterize the potential risk to human health and the environment. The results of the RI will be used to develop strategies for timely and cost-effective remediation of metals contamination at and in the vicinity of the Site.

Based on previous soil investigations, the heavy metals antimony, arsenic, cadmium, copper, lead, manganese, mercury, vanadium, and zinc are identified as the contaminants of concern in the tailings piles and surrounding soil. A Conceptual Site Model was developed to evaluate the migration pathways of those contaminants from the source to human and environmental receptors. Physical migration pathways included surface water migration during storm water runoff from the tailings piles and surrounding impacted soil, and airborne migration during wind erosion and dust-generating activities. Chemical migration pathways included storm water runoff that could pick up metal ions from tailings piles, transport the contaminants offsite, and release the metal ions during an exchange with soil or other fluid. Groundwater was not identified as a migration pathway. Human receptors include residents that live on adjacent properties where soil contamination is present. Ecological receptors include aquatic animal species such as fish and amphibians; and various terrestrial, mammal, bird and reptile species that would contact contaminated surface water or stream sediments.

There were no detected exceedances of the AWQS for either total or dissolved metals in existing monitoring wells located on the Site. Lead exceeded the AWQS of 0.05 mg/L in the sample collected from the well on parcel 110-47-001m on August 29, 2007. Analytical results prior to and after this sampling event indicate lead concentrations below the laboratory reporting limit, and consequently the AWQS. Metal concentrations did not exceed the AWQS in the other three domestic water wells sampled. The well located on parcel 110-47-001m is located in close proximity to Laurel Creek, which receives run-off of metals-impacted material from the Grand Reef Mine. Further monitoring of this domestic well is recommended.

The soil analytical results for lead and arsenic were plotted on maps to show the lateral extent of contamination at and in the vicinity of the Site. In addition, the vertical extent of contamination was shown on maps for three sampling depths: 6 inches, 12 inches and 24 inches. The maps show



elevated concentrations of lead and arsenic contamination at and adjacent to the Site, including high concentrations of heavy metals at a small historical mill site on Parcel 110-47-006 east of the Site. In addition, lead and arsenic contamination is present on the Laurel Creek alluvial fan that extends southwestward out of Laurel Canyon. These results indicated that in addition to the historic milling activities and tailing piles, windblown or surface water movement of metals contamination as well as other sources of metals contamination may exist in the vicinity of the Site including Grand Reef Mine.

The floodplain delineations indicate that both the Aravaipa Creek and Laurel Creek 10-, 25-, 50-, and 100-year floodplains affect both the Upper and Lower Tailings Piles. Scour analysis and erosion protection to protect the tailings piles from the sheet flow were considered in the flood protection designed for the Upper Tailings Pile were considered in the 2006 Geomorphological Report.



## 12.0 REFERENCES

- Apello, T., 2006. *Arsenic in Groundwater- A World Problem*. International Association of Hydrogeologists Symposium, Utrecht.
- Arizona Administrative Code (AAC), Title 18-Environmental Quality, Chapter 11, Article 4- Aquifer Water Quality Standards. Effective August 14, 1992.
- Arizona Administrative Code (AAC), Title 18-Environmental Quality, Chapter 7, Article 2-Soil Remediation Standards. Appendix A. Effective May 5, 2007.
- Arizona Administrative Code (AAC), Title 18-Environmental Quality, Chapter 11 Article 4- Aquifer Water Quality Standards. Appendix A Numeric Water Quality Standards. Effective January 31, 2009.
- Arizona Department of Environmental Quality, 1993. The Klondyke Tailings and Aravaipa Creek Water Quality, March and April.
- Arizona Department of Environmental Quality (ADEQ). September 1996, *A Screening Method to Determine the Soil Concentrations Protective of Groundwater Quality*.
- Arizona Department of Environmental Quality, 1997. Klondyke Site and Vicinity Laboratory Reports.
- Arizona Department of Environmental Quality, 2007. Community Involvement Plan, Klondyke Tailings WQARF Site.
- Arizona Department of Water Resources, 2002a. Aravaipa Canyon Basin, <http://www.azwater.gov/azdwr>.
- Arizona Department of Water Resources, 2002b. Registered Wells in Arizona Inventory database.
- Arizona Department of Water Resources, 2002c. Groundwater Site Inventory (GWSI) database, <http://www.azwater.gov/azdwr>.
- Arizona Game and Fish Department, 2013. Element Status Designations by Common Name. [http://www.azgfd.gov/w\\_c/edits/hdms\\_species\\_lists.shtml](http://www.azgfd.gov/w_c/edits/hdms_species_lists.shtml)
- Arizona Meteorological Network, 2007. <http://ag.arizona.edu/azmet/>, accessed November 30.
- Cannon Microprobe, 2002. Electron Microprobe, Scanning Electron Microscope and X-Ray Diffraction Analysis of Klondyke Soil and Tailings Samples. Prepared for URS Corporation.



- Dames & Moore, 2000. Technical Memorandum, Lead Speciation, Lead and Arsenic Bioavailability, Klondyke Tailings WQARF Site. Prepared for Arizona Department of Environmental Quality.
- Ecology and Environment, Inc., 2010. Klondyke Tailings Residences Removal Assessment Report. Prepared for U.S. Environmental Protection Agency.
- Ecology and Environment, Inc., 2012. Klondyke Tailings Removal, Additional Sources Investigation Letter Report. Prepared for U.S. Environmental Protection Agency.
- Ecology and Environment, Inc., 2014. Klondyke Tailings Removal Report. Prepared for U.S. Environmental Protection Agency.
- Fuller, J.E., 2000. Aravaipa Canyon Geohydrology Assessment. U.S. Fish and Wildlife Service Contract Number 20181-99-C016.
- Fuller, J.E., 2002. Memorandum, Klondyke Tailings Erosion Study. J.E. Fuller/Hydrology & Geomorphology, Inc. Prepared for URS Corporation.
- Fuller, J.E., 2006. Aravaipa Creek Erosion Analysis, Post 2006 Flood. J.E. Fuller/Hydrology & Geomorphology, Inc. Prepared for URS Corporation.
- Graf, W.L., 1997. Field Investigations, Fluvial Geomorphology of Aravaipa Creek in the Vicinity of Klondyke, Arizona. Prepared for SCS Engineers, Project No. 10.96043.00, Phoenix, Arizona, 20p.]
- Hadley Associates, 1991. Environmental Changes in Aravaipa, 1870 – 1970. An Ethnoecological Survey. Hadley Associates. Prepared for Arizona State Office of U.S. Bureau of Land Management.
- HydroGeoLogic, Inc., 2012. Final Letter Report – Remedial Investigation Klondyke Tailings WQARF Registry Site. HydroGeoLogic, Inc. Prepared for Arizona Department of Environmental Quality.
- Minckley, W.L. 1981. Ecological studies of Aravaipa Creek, central Arizona, relative to past, present, and future uses. Unpublished report to USDI, Bureau of Land Management, District Office, Safford, Arizona. Final Report, Contract No. YA-512-CT6-98. 362 pp.
- Morfin, O.T., 2003. *The Use of Pb Isotopes to Characterize the Fate and Transport of Lead (Pb) in an Interrupted Stream, Aravaipa Creek, Graham County, Arizona.*
- Morin and Hutt, 1998. from Statics Test
- Rhea, Milton, 2004. Former Athletic Mill Company employee, personal communication with Kirsten Erickson, June 4.
- SCS Engineers, 1998. Klondyke Tailings Response Strategy Analysis, Graham County, Arizona. Prepared for Arizona Department of Environmental Quality.



Sellers, W.D. and Hill, R.H., 1974. Arizona Climate 1931-1972, The University of Arizona Press, Tucson, Arizona.

Soil Conservation Service, 1973. General Soil Map Graham County, Arizona, United States Department of Agriculture.

Turnbull, Clay, and Alice Turnbull, 1990. Interview. Audio tape on file, Safford Field Office, Bureau of Land Management, Safford.

URS Corporation, Risk Assessment Methodology, Klondyke Tailings WQARF Site.

URS Corporation, 2003b. Final Geochemistry Static Test Report, Remedial Investigation, Klondyke Tailings WQARF Site. Prepared for Arizona Department of Environmental Quality.

URS Corporation, 2003a. Final Geochemistry Kinetic Test Report, Remedial Investigation, Klondyke Tailings WQARF Site. Prepared for Arizona Department of Environmental Quality.

URS Corporation, 2004a. Final Biological Survey Report, Klondyke Tailings Remedial Investigation/Feasibility Study. Prepared for Arizona Department of Environmental Quality.

URS Corporation, 2004c. Final Geophysical Survey Report, Klondyke Tailings WQARF Site. Prepared for Arizona Department of Environmental Quality.

URS Corporation, 2004b. Final Cultural Resources Survey for the Klondyke Tailings Remedial Investigation/Feasibility Study. Prepared for Arizona Department of Environmental Quality.

URS Corporation, 2005. Klondyke Tailings Site Soil Boring Logs and Well Construction Diagrams, Klondyke Tailings WQARF Site.

URS Corporation, 2006a. Final Work Plan, Remedial Investigation, Klondyke Tailings WQARF Site.

URS Corporation, 2006b. Klondyke Soils Data Verification Memorandum, Klondyke Tailings WQARF Site.

URS Corporation, 2006c. Klondyke Groundwater Data Verification Memorandum, Klondyke Tailings WQARF Site.

URS Corporation, 2006d. Final Early Response Action Completion Report, Klondyke Tailings WQARF Site.

URS Corporation, 2008. Land and Water Use Study Questionnaire, Klondyke Tailings WQARF Registry Site.



URS Corporation, 2013a. Final Site Characterization Report, Klondyke Tailings WQARF Registry Site.

URS Corporation, 2013b. Review of the EPA Bioavailability Memorandum.

U.S. Environmental Protection Agency, 1994. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846, Third Edition).

U.S. Environmental Protection Agency, 1998. Environmental Technology Verification Report, Field Portable X-ray Fluorescence Analyzer. EPA/600/R-97/145.

U.S. Environmental Protection Agency, 2011. Bioaccessibility of Lead Associated with Klondyke Tailings Samples. Draft. 7/22/11.

VSI Environmental, 2008. Air Monitoring Report, Klondyke Tailings WQARF Site.

Welch, A.H., Lico, M.S., and J.L. Hughes, 1988. Arsenic in Ground Water of the United States. *Ground Water*, Vol. 26, No. 3, pp. 333-347.

WRCC (Western Regional Climate Center), 2007. <http://www.wrcc.dri.edu/>, accessed November 30.

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